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A penpoint gunnel, *Apodichthys flavidus*, photographed by the late Ben Patten of the Northwest and Alaska Fisheries Center, NMFS, NOAA.

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The Feasibility of Enhancing Red Sea Urchin, *Strongylocentrotus franciscanus*, Stocks in California: An Analysis of the Options

MIA J. TEGNER

Introduction

The red sea urchin, *Strongylocentrotus franciscanus*, is the largest echinoid in kelp forest communities along the west coast of North America and is fished commercially from British Columbia to Baja California (Sloan, 1986). The California sea urchin fishery began in the early 1970's and grew very rapidly to total landings of more than 20,000 metric tons (t) in 1987 (Kato and Schroeter, 1985; Parker[1]). By 1987, this was the second most valuable fishery in California waters with a landed value of $13,693,000. There are no unfished stocks left in southern California; only the development of a northern coastal fishery in the mid 1980's allowed the continued increase in landings (Fig. 1).

With the eventual elimination of unfished stocks statewide, and potentially throughout the range of the fishery, the alternatives are a reduced harvest and contraction of the industry, or stock enhancement to maintain populations above what is possible with current fishery practices. The spectacular successes achieved with some finfishes, notably the salmonids, as well as the many recent advances in aquaculture, have led to widespread interest in the second and more economically appealing alternative. Here, I examine potential options for the enhancement of red sea urchin stocks, consider the conditions under which each might be appropriate, and make relative estimates of the costs and effort involved.

The concept of stock enhancement for valuable invertebrate fisheries is not new. Transplantation of abalones, *Haliotis* spp., to better habitats for growth dates to the 19th century (Ino, 1966), and lobster, *Homarus* spp., juveniles were cultured for release on fishing grounds as early as the 1880's (Van Olst et al., 1980). The Japanese in particular have explored a variety of methods to enhance fishable stocks. The success of all attempts to enhance benthic invertebrate stocks by the release of hatchery-reared juveniles will be reviewed, as well as other methods relevant to sea urchins. Because the success of many Japanese approaches is related to the structure of their fishing industry, this and the implications of the American tradition of open-access fisheries for stock enhancement will be discussed.

Figure 1.—California landings of red sea urchins, 1971–87 (Calif. Dep. Fish Game. Unpubl. data).

The success of any enhancement effort will depend upon the answer to a critical question: What stages in the life history of the organism limit the production of fishable stocks? For red sea urchins, the limiting factors could be larval supply, problems associated with settlement, survival of newly settled to mid-sized animals, or adequate

[1]D. Parker, Calif. Dep. Fish Game, 330 Golden Shore #50, Long Beach, California 90802. Unpubl. data, 1989.

ABSTRACT—The California fishery for red sea urchins, Strongylocentrotus franciscanus, *has undergone explosive growth in recent years and is approaching full exploitation. Thus, there is considerable interest in enhancing stocks to maintain a high rate of landings. Fishable stocks of red sea urchins in different areas appear to be limited at three stages in their life history: By the availability of larvae, by the survival of newly settled to mid-sized animals, and by the food available to support growth and reproduction of larger animals. Here I review other efforts, notably the extensive Japanese work, to enhance fishable stocks of benthic marine invertebrates, and consider the potential options for red sea urchins at different points of limitation. These include collecting or culturing seed for outplanting, physical habitat improvement measures, improving the food supply, and conservation measures to protect existing stocks until alternate methods are proven and in place. The options are compared in terms of biological feasibility, capital and labor requirements, and potential implications for change in the structure of the fishing industry.*

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food to support growth and/or gonad production. Enhancement efforts which do not address the stage which limits production are not likely to be successful; e.g. seeding of juveniles will do little for a population limited by survival of mid-sized animals or food supply. Furthermore, these factors are likely to vary on local and regional scales, e.g. the survival of mid-sized animals correlates negatively with the abundance of two warm temperate predators, spiny lobsters, *Panulirus interruptus*, and California sheephead, *Semicossyphus pulcher* (Tegner and Dayton, 1981; Tegner and Barry[2]). The northern range limit of these two predators is normally Point Conception, and both are characteristic of bottoms with considerable vertical relief; they will have little impact on red sea urchins north of southern California or in pavement habitats. Finally, enhancement methods will vary considerably in costs, in the length of time required to achieve results, and in how long the results will last.

Summary of the Life History of Red Sea Urchins

The biology of *S. franciscanus* has recently been reviewed by Kato and Schroeter (1985). Here I will summarize aspects of the life history relevant to factors potentially limiting the size of fishable stocks.

The timing and length of the spawning season of red sea urchins are highly variable among locations (Kato and Schroeter, 1985). Seasonality may be related to the patterns of food availability (Bernard, 1977); red sea urchins in the Point Loma kelp forest near San Diego, where food is generally abundant, are thought to spawn throughout the year although there is a winter peak. North of southern California, where food may be primarily available from mid spring to mid fall (Ault, 1985), the spawning season is reported from late spring to early summer or even fall. The length of the planktonic larval phase is temperature dependent. Strathmann (1978) reported a range of 62–131 days for larvae cultured at ambient temperatures (generally 7°–13°C) in Friday Harbor, Wash., and Cameron and Schroeter (1980) found the earliest settlement at 40 days and the peak at 50 days after fertilization for larvae cultured at 12°C. Whatever the temperature, the length of the planktonic phase indicates that the distribution of the larvae is strongly affected by current patterns.

Current patterns, and thus the fate of sea urchin larvae, vary seasonally and with latitude. Parrish et al. (1981) divide the California Current System into four oceanographic regions on the basis of mean geostrophic flow, Ekman transport, and wind stress curl patterns. California falls into two of these regions, the region of maximum upwelling from Cape Blanco to Point Conception which includes the northwestern Channel Islands, and the Southern California Bight. The region of maximum upwelling is characterized by strong offshore surface transport during the spring and summer, whereas the Southern California Bight is an area of minimal upwelling and a closed gyral circulation (Parrish et al., 1981). These oceanographic patterns appear to have major implications for the transport of larvae. The Southern California Bight, the area of minimal upwelling, has the highest known rates of red sea urchin recruitment (to the population) throughout its range (Sloan et al., 1987). Ebert and Russell (1988) report reduced recruitment of intertidal purple sea urchins (*S. purpuratus*) on headlands, predictable sites of upwelling, compared with areas without predictable upwelling within the region of maximum upwelling. Roughgarden et al. (1988) found a negative correlation between a season's recruitment of barnacles, *Balanus glandula,* and the upwelling index at Pacific Grove. Tegner and Barry[2] analyzed red sea urchin recruitment patterns on the Channel Islands of southern California. Recruitment was highest on the southeastern islands, those most affected by the Southern California Eddy, the closed gyral circulation of Parrish et al. (1981), which appears to aid in the retention of larvae, and was very low on the northwestern islands until the 1982–84 El Niño when upwelling rates were extraordinarily low. While little red sea urchin recruitment data is available from the region of maximum upwelling, it is reasonable to assume that stocks in central and northern California are more likely to be limited by larval supply than those in southern California.

The settlement requirements for red sea urchin larvae are poorly understood. Hinegardner (1969) reported that both red and purple sea urchin larvae settle on an algal and bacterial film. Cameron and Schroeter (1980) observed no substrate specificity among several filmed natural substrates and suggested that sea urchin larvae settle on any surface they encounter once they became competent to undergo metamorphosis. Rowley (1989) found that purple sea urchin larvae settle at significantly higher rates in response to crustose coralline algae and red algal turf than in response to filmed rocks, but was not able to demonstrate density differences among natural substrates for newly settled (<1 mm) red sea urchins. Thus, evidence to date suggests that suitable substrates for settlement are not likely to be limiting as long as excessive sedimentation or pollution are not an issue.

In contrast, the survival rates of newly settled to mid-sized animals do appear to limit the size of fishable stocks in some populations. While red sea urchin larvae do not settle in response to adults (Cameron and Schroeter, 1980), juvenile abundance is often highest underneath the test or spine canopies of conspecific adults (Fig. 2), especially where the substrate affords little cover or in the presence of certain predators (Tegner and Dayton, 1977; Sloan et al., 1987). Breen et al. (1985) have shown experimentally that the spine canopy association is a result of juvenile behavior;

[2]Tegner, M. J., and J. P. Barry. Size structure of red sea urchin (*Strongylocentrotus franciscanus*) populations in southern California; effects of growth, recruitment, predation, and oceanography. Manuscr., 61 p. A-001, Scripps Inst. Oceanogr., La Jolla, CA 92093.

juveniles chose shelter under adults over other protective locations. This association appears to be critical to the recruitment success of this species. Tegner and Dayton (1977) observed both significantly reduced settlement and survival of previously settled juveniles on experimentally fished (all animals >95 mm were removed) reefs in the Point Loma kelp forest near San Diego. The spine canopy association provides juveniles protection from predators such as spiny lobsters (Tegner and Levin, 1983) and the young feed on drift algae snared by the adults (Tegner and Dayton, 1977; Breen et al., 1985). Depending upon the size of the shelter provider and bottom topography, juveniles eventually become too large for the spine canopy association and must move away from adults. This size category (~ 25–30 mm) of red sea urchins is highly vulnerable to predation (Tegner and Levin, 1983) and Tegner and Barry[2] have shown that survival of second year (~ 36–60 mm) animals limits the size of fishable stocks on the southeastern Channel Islands. Red sea urchins appear to attain a partial refuge in size at about 90 mm from spiny lobsters and sheephead, their major predators in southern California (Tegner and Levin, 1983). However, red sea urchins of all sizes are susceptible to predation by sea otters, *Enhydra lutris*, the major predator in central California.

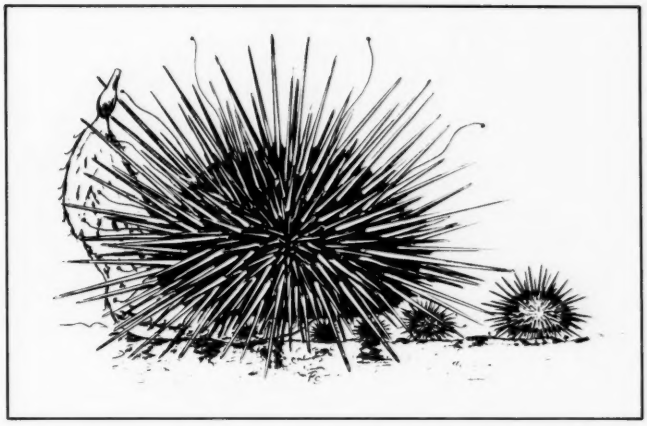

Figure 2.—Juvenile red sea urchins shelter under the spine canopies of conspecific adults and share in the food caught by the larger animal. As the recruits grow, they move toward the periphery of the spine canopy. (From Tegner and Dayton, 1977; copyright 1977 by AAAS.

Finally, fishable stocks may be limited by the amount of food available to support growth and/or reproduction. The relationships between food availability, sea urchin behavior and physiology, and kelp forest community structure have been well studied in recent years (Lees, 1970; Pearse et al., 1970; Mattison et al., 1977; Dean et al., 1984; Ebeling et al., 1985; Harrold and Reed, 1985). In a healthy kelp forest, red sea urchins feed on the abundant algal drift produced by *Macrocystis pyriferia* and other laminarians. When food is plentiful, the animals remain in cryptic habitats and move little. When drift algae become limiting, whether from an increase in grazing pressure, or a decrease in drift availability due to loss of algal standing stocks from such disturbances as storms or El Niños, urchins will leave their protective habitats and forage on attached plants. Moving sea urchins may denude large areas of kelps and, in extreme cases, grazing may eliminate and prevent the recovery of all algae except coralline algae. Sea urchins in barren grounds may persist, but gonad development is poor, and with time, the population may come to consist mainly of small individuals. In addition to their reproductive function, sea urchin gonads function as the main nutrient storage organ (Giese, 1966); as a result, starved sea urchins will resorb their gonads to stay alive (Holland et al., 1967). Starved sea urchins will not grow and they may even shrink in size (Ebert, 1967). Thus, the relative size of the gonad, or gonad index (ratio of gonad to total body volume or weight), is a commonly used estimate of urchin nutritional status (Pearse et al., 1970) which reflects both the quantity and quality of food available (Lees, 1970; Vadas, 1977; Larsen et al., 1980; Harrold and Reed, 1985). Gonad color, a factor in the salability of roe, is also dependent upon the type of food eaten (Mottet, 1976a).

Red sea urchins are highly selective in their choice of algal food and exhibit distinct species preferences. In southern California, Leighton (1966) found that *Macrocystis* was significantly preferred over other algae. Species of intermediate preference included *Gigartina armata (spinosa), Laminaria farlowii, Eisenia arborea, Pterygophora californica*, and *Egregia laevigata*; least preferred was *Cystoseira osmundacea*. In the San Juan Islands of Washington, Vadas (1977) found *Nereocystis luetkeana* to be most preferred, followed by *Costaria costata* and *Laminaria saccharina*; two species of *Agarum* were actively avoided. Laboratory and field studies have shown that sea urchins eating their most preferred foods grow more rapidly, and have higher food and energy absorption, growth efficiency, and reproductive potential than animals feeding on less preferred foods. On the other hand, growth rates and gonad index of animals switched to a diet of their least preferred food drop significantly, apparently because so little algae is eaten. While sea urchin feeding in nature is a compromise between preference and availabil-

ity, preferential feeding appears to be a strategy designed to maximize growth and reproduction (Vadas, 1977; Larson et al., 1980).

Enhancement of Fishable Stocks Limited by Larval Supply

Brood Stock Protection

Brood stock protection is one of the oldest fishery management approaches to maintaining adequate larval supply. In the early days of the red sea urchin harvest in California, fishermen focussed on relatively few areas, typically those close to ports and international airports. Unfished areas continued to produce larvae. With the expansion of the fishery in the last few years, California can no longer count on unfished stocks to repopulate harvested areas. While red sea urchins become sexually mature between 40 and 50 mm (Bernard and Miller, 1973; Kato and Schroeter, 1985; Tegner and Barry[2]), small animals contribute few gametes for the next generation. A plot of gonad weight as a function of test diameter (Fig. 3) shows that the increase in gonad production is exponential with size; the largest animals contribute a disproportionately large share of gametes to the population. Thus, animals smaller than the legal minimum size of 76 mm are not capable of maintaining larval production at previous rates.

To ensure brood stock protection of their sea urchin populations, the Japanese have taken a threefold approach (Mottet, 1976a). There are minimum size regulations to allow reproduction and to ensure adequate product size. The actual spawning season is closed to fishing, ensuring that reproduction will take place and that sea urchins will not be harvested when the roe quality is poor. Finally, many small sites are designated as "no fishing" areas, an action which also protects recruits. Some sites, known as good recruitment areas from which young sea urchins migrate into fishing areas as adults, are permanently closed. Other sites are fished in 3-year cycles. Harvestable sea urchins are fished out in the first year of the cycle, allowing luxuriant algal growth and presumably minimizing competition of juveniles with the adults for food while maximizing growth rates. These animals are taken at the beginning of the next 3-year cycle. Mottet (1976a) reports that the resulting high density of legal-sized sea urchins greatly increases the efficiency of harvesting.

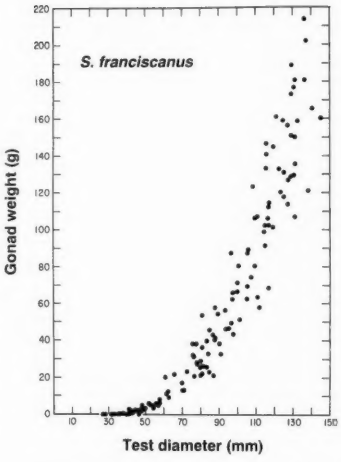

Figure 3.—Gonad weights of 138 *Strongylocentrotus franciscanus* collected from one location in the Point Loma kelp forest in December 1975. (From Tegner and Levin, 1983).

Implications for red sea urchins: Assuming that the existing minimum size limit will not provide adequate larval production, what measures are potentially available under the category of brood stock protection? The State of Washington has both a minimum and a maximum size limit (Sloan, 1986), and Kato and Schroeter (1985) have suggested that this may also be useful in California. Furthermore, the roe of the largest sea urchins (>125 mm) has been reported to be of generally inferior quality[3]. The usefulness of a maximum size limit to provide some degree of brood stock and nursery (see the "Habitat Improvement" section on p. 12) protection depends upon the number and density of sea urchins that have been left behind by the fishery. Significant densities are critical because fertilization efficiency declines rapidly over distances as small as 20 cm between spawners (Pennington, 1985), but where the numbers are adequate, this may be a simple and effective approach.

Because the actual period of spawning is highly variable in both time and space, this may be impractical to legislate but could potentially be controlled at the level of the processor. This approach works in Japan because of the high degree of local control over fisheries (Mottet, 1976a). The State of Washington has also adopted a simple system of rotating fishing closures; sea urchin grounds are divided into three zones, one of which is closed each year to foster repopulation (Kato and Schroeter, 1985). The Japanese approach of closing sea urchin recruitment habitats permanently would not work with *S. franciscanus* because of the spine canopy association; juveniles are abundant in the same habitat as adults (Tegner and Dayton, 1977).

Wild Seed Collection

When natural recruitment rates appeared to be the major factor limiting sea urchin population size, the Japanese began experimenting with a variety of collectors on which larvae would settle directly, thus presumably bypassing sources of mortality associated with settlement in their natural habitat. Some of the earliest collectors were apparently slate surfaces covered with tufts of nylon thread (300 denier thread at a density of 30 threads/cm^2) (Mottet, 1981). Eight months after being placed in the sea, these collectors averaged 1,200 sea urchins of about 2 mm test diameter per m^2. Long (80 mm) tufts were found to be less susceptible to overgrowth by fouling organisms than short (10 mm) tufts.

Biologists in Hokkaido, one of the three major sea urchin producing areas in Japan (Takagi, 1986), conducted extensive studies on the collection of wild seed of *S. intermedius*, their in-

[3]R. M. Harbo. Personal commun. cited in Sloan (1986).

termediate culture, and release back into the natural habitat (Department of Mariculture, Hokkaido Central Fisheries Experimental Station, 1984; Kawamura, 1987). Previous efforts in sea urchin propagation in Hokkaido had included policies for resource control, transplantation, and creation of fishing grounds, but it was felt that further increase required large numbers of seed. After observing that sea urchins settled abundantly on scallop culturing facilities, a decade-long research project was initiated to pursue collection of wild seed. Extensive studies related the spawning period to the fall drop in water temperature, determined the distribution of larvae of various stages in time and space, investigated the direction and velocity of currents, and assessed annual variability in larval availability. They found that settlement was from December to January, and that by June, the density of young-of-the-year sea urchins in natural habitats on the coast was consistently below 15 /m^2 but usually greater than 100/m^2 on a collecting apparatus. Furthermore, there was a sharp decrease in abundance (average mortality, 65 percent; range, 43–96 percent; $n = 5$ years) in the natural habitat from spring to fall which is attributed to predation by crabs and seastars and, when temperatures exceed 22°–23°C, to thermal stress.

A large variety of materials and designs for collectors were field tested using different suspension systems and periods of installation in several locations. The most successful collector was constructed from transparent vinyl chloride plates with a corrugated surface called wave plates (Fig. 4). The transparent plates allowed algae to grow on both sides, increasing the surface available for settlement. Three square plates, 30 cm on a side, were suspended vertically in a layered configuration with the corrugations running horizontally. Arrays of this arrangement (Fig. 5) led to the adherence of an annual average of 197 sea urchins per collector (range 42-836; n = 9 years) in January-February at one location in western Hokkaido. The numbers adhering were strongly

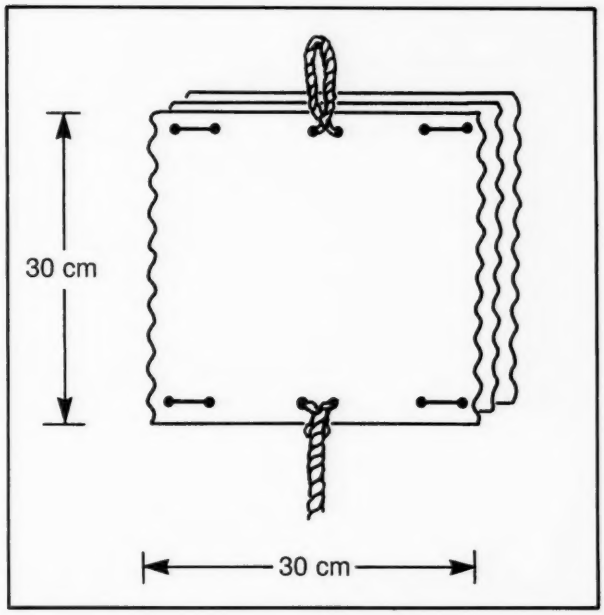

Figure 4.—Diagram of a collector used in Hokkaido for settlement of sea urchin larvae from the plankton. The corrugated (wave) plates are constructed of transparent vinyl chloride. Dimensions are in centimeters. Dep. Maricult., Hokkaido Central Fish. Exper. Sta., 1984)

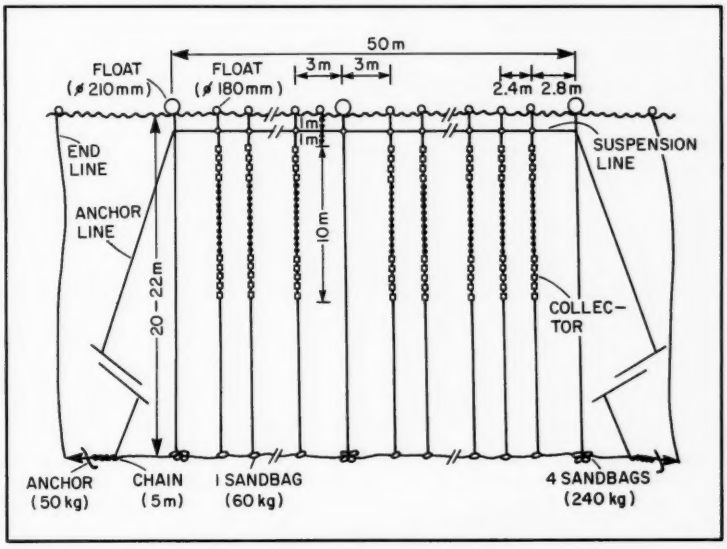

Figure 5.—Diagram of a fixed suspension sea urchin seed collecting facility. (Dep. Maricult., Hokkaido Central Fish. Exper. Sta., 1984).

affected by depth of the installation; 20–30 m bottom depths with the plates suspended at intermediate levels appeared to be optimal. The plates were most successful when installed 3 months before the settling season began.

By April-May of all years studied, the number of adhering sea urchins had decreased from earlier in the year; wave-induced oscillation of the collectors caused animals to drop off once they get to about 3 mm. The high predation rates on small animals during their first spring and summer in the natural habitat, combined with the drop-off problem from culture plates, necessitated going to intermediate culture to ensure good survival rates. Intermediate culture may be carried out in baskets in the sea or in tanks on land. Net baskets (80 × 80 × 40 cm), constructed of 1 or 2.8 mm mesh, were designed to hold 20 seed collectors. In late March, before the drop-off problem becomes serious but after the sea urchins are large enough to be retained by the mesh, the collectors are inserted into the baskets. By the time the seed get to 5 mm, the food adhering to the wave plates is gone, so the collectors are removed and algae is added to the baskets. With 5–6 months of feeding, it is possible to culture sea urchins to release size of about 15 mm by October. A single basket can accommodate 2,000 sea urchins for intermediate culture in the ocean and still allow good growth with survival rates up to 80–90 percent. In onshore culturing facilities, slightly smaller baskets were suspended in seawater-filled tanks with the incoming water sprinkled on top. This arrangement and a 3 mm mesh allowed adequate circulation to maintain water quality. The comparative advantages and disadvantages of offshore and onshore culture are detailed in Table 1. In some areas where algal food is not easily available during the summer, experiments have shown that juvenile sea urchins grow very well on leaves of a terrestrial plant called knotweed, *Polygonum sachaliense*.

The survival rate of seed settled on collectors varies with the size and time of release into the benthic habitat. If the seed are allowed to fall naturally from the collectors, or kept in intermediate culture until a size of about 5 mm (June), survival rate is less than 10 percent by fall. As with the wild seed, this summer decrease is attributed to predation. Survival was variable but much higher for seed kept in intermediate culture until fall. Averaging the results from three experiments where the seed were released at 15–20 mm test diameter, the survival rate was 60 percent 1 month after release, and in the three experiments, 24–75 percent at 1 year. Thus, this study established the technical basis for natural seed collection, intermediate culture, and release of *S. intermedius*. In the years 1980–82, a total of 4,068,700 seed were collected and processed through intermediate culture, but the impact on fishery landings 2–2.5 years after release was not reported (Department of Mariculture, Hokkaido Central Fisheries Experimental Station, 1984).

Subsequent studies (Miyamoto et al., 1985) considered the characteristics of juvenile sea urchins obtained from collectors to minimize mortality during handling and after return to the natural environment. Small (3.2 ± 0.5 mm) but not larger (>7 mm) animals grew on microflora. Experiments with predators showed that the smaller the sea urchin, the higher the predation rate. Sea urchins >10 mm were not consumed by the local seastar, and few of the tested crabs consumed sea urchins ≥13 mm. Finally, the tolerance to air exposure was determined to be temperature dependent, and brief (30–60 minute) exposures to low salinity seawater impaired the vitality of the seed as measured by the time required for animals to turn over.

Implications for red sea urchins: The experience of the Marine Biomass Project (North et al., 1981) suggests that California sea urchins will readily settle on artificial substates. W. North[4] reports that thousands of red and purple sea urchins settled on a large (32 m diameter) structure designed to test the feasibility of growing *Macrocystis* in the open ocean. The "Test Farm" was deployed about 6 km off Corona del Mar, Calif., in about 550 m of water in September 1978. The arms supporting the kelp plants were at about 20 m depth but other structures of the farm extended to the surface. North reports that sea urchins settled, probably very soon after installation, all over the structure. Some were on I-beams which offered a ledge for support; many others settled on smooth, cylindrical structures. By August 1979, the sea urchins had grown enough to destroy juvenile *Macrocystis* colonizing the central buoy. There were more purple than red sea urchins, but North estimates that the abundance of *S. franciscanus* was probably adequate to warrant collections for stock enhance-

Table 1.—A comparison of onshore vs. offshore intermediate culture of sea urchin seed (Department of Mariculture, Hokkaido Central Fisheries Experimental Station, 1984).

Item	Onshore	Offshore
Preservation of facilities	Easy	Susceptible to wave damage
Management of culture	Can be done intensively with a small staff	Intensive management is difficult
Capital costs	High	Low
Maintenance costs	High	Often low
Stability of the culture environment (e.g., water temperature and quality)	Apt to become unstable, but artificial control is possible	High stability, but artificial control is difficult
Seed health	If control is deficient, apt to become weak	Healthy in many cases

[4]W. North, Kerckhoff Marine Laboratory, 101 Dahlia Street, Corona del Mar, CA 92625. Personal commun., 1989.

ment. It may be possible to minimize the proportion of purple sea urchins settling by manipulating the depth of the collectors.

Larval Releases

While the seeding of hatchery-reared abalones is practiced on a large scale in Japan (Kafuku and Ikenoue, 1983), experiments in California do not support this as a cost-effective approach to stock enhancement (Tegner and Butler, 1985, 1989). Problems include the high cost of seed cultured for about a year, high predation rates after seeding, and low recovery rates of live animals. Furthermore, hatchery-reared seed behave differently than wild abalones of the same size, apparently increasing their susceptibility to predation (Schiel and Welden, 1987; Tegner and Butler, 1989). In an effort to develop a more natural and less costly seeding technique, experiments tested the release of late stage, competent-to-settle larvae (Tong et al., 1987; Tegner et al.,[5]). Theoretically, this approach is appealing because of the very low production and release costs, and inappropriate behavior patterns should not be an issue. Larvae were released by waders into the shallow subtidal (Tong et al., 1987) or into kelp forests with appropriate rocky habitats by divers (Tegner et al.,[5]). Both studies demonstrated enhancement of existing populations at time periods ranging from 3 to 12 months after larval release, but the results should be considered preliminary until better success rates can be achieved.

Seeding Hatchery-Reared Juveniles

Seeding is an attractive approach to stock enhancement for several reasons. In contrast with nature, 100 percent fertilization can be achieved and heavy larval losses to predation, starvation, and transport to inappropriate habitats are avoided. Mortality of highly vulnerable, newly settled individuals is also presumably greatly reduces by holding seed in the laboratory for several months to a year. Furthermore, as seeding in theory reduces the fishing pressure on wild stocks, it may allow managers to avoid more painful restrictions on broodstock harvest.

Experience with Other Benthic Marine Invertebrates

The earliest efforts to enhance fishable stocks of benthic marine invertebrates by the production and release of cultured juveniles apparently involved homarid lobsters. Van Olst et al. (1980) report that between 1885 and 1920, more than 22 lobster hatcheries were established in New England, the Maritime Provinces of Canada, and Europe. The method involved stripping eggs from gravid females and rearing the larval stages under presumably optimal conditions, i.e. the absence of predation, appropriate food the temperature, and disease treatment. However, it was eventually determined that the eggs were maintained and hatched more efficiently by the females than in culture. Furthermore, because of the problems of tagging lobsters, it was difficult to assess the results of the restocking programs, and the effort was reduced considerably. By 1980, there were only two hatcheries seeking to augment natural stocks by the release of hatchery-reared animals (Van Olst et al., 1980).

Nevertheless, lobsters remain an advantageous animal for culture (high value; tolerance to temperature, salinity, and water quality changes; large size of the larvae; acceptance of inexpensive, dead foods), and recent field studies suggest that survival after release is strongly related to habitat suitability. Howard (1982) proposed that rearing animals beyond metamorphosis followed by placement on substrata (whether natural rock beds or augmented with artificial structures) with an appropriate number and size of interstices would repay the expense of longer time in culture. A new set of studies is currently underway in Great Britain. The internally placed microtags developed for salmonids were adapted for use with juvenile (9–15 mm carapace length) *Homarus gammarus* (Wickins et al., 1986). Tag retention was 85–100 percent as the animals passed through up to 29 molts (90–102 mm carapace length) in captivity. Field releases of tagged individuals were conducted in 1983 and 1984; tag returns from the fishery are expected 5 years later (Walker, 1986). Scuba divers captured five individuals 1 year after release, suggesting that juveniles remain in the area and can survive in the wild. French scientists in Brittany are releasing hybrid American-European juvenile lobsters (which are easily distinguished from natives) in another attempt to determine whether hatchery-reared animals contribute to fishable stocks (Munro, 1982).

Seeding of hatchery-reared juvenile abalones to enhance fishable stocks, practiced on a large scale in Japan, has been reviewed by Grant (1981), Kafuku and Ikenoue (1983), and Uki (1984). After the loss of many abalone beds to overfishing, industrial and domestic pollution, or the loss of algal food, there was much incentive to enhance stocks of this valuable gastropod. Abalone aquaculture has been studied since the early 1960's and techniques for mass culture have been worked out. Advances in conditioning adults, spawning induction, controlling fertilization and larval settlement, and suitable food for the postlarvae have made culture very successful. By 1979, 42 culture centers using standardized techniques produced a total of 11,658,000 seed, almost all for release into the sea. However, despite this large-scale seeding effort, Kafuku and Ikenoue (1983) report that "the number released is too low to determine whether there is any effect on (the total national) catches." These authors document a slow decline in the national harvest from 1970 to 1979.

Published survival rates from abalone seeding experiments in Japan, reviewed by Saito (1984), range from less than 1 to 80 percent. As many studies found decreasing mortality with increasing seed size, fishing cooperatives generally rear the 20–30 mm seed received from the hatcheries

[5]M.J. Tegner, E.E. Ebert, and D.O. Parker, A-001, Scripps Institution of Oceanography, La Jolla, CA 92093. Unpubl. data.

in intermediate culture for an additional year (to a size of 40–60 mm) before release onto the fishing grounds (Uki, 1984). Various habitat improvement structures, such as baskets or cement bins filled with boulders or concrete blocks engraved with slits, are believed to enhance survivorship (see "Habitat Improvement" section, p. 12) and allow for planting at a smaller size. In Hokkaido, both wild-collected and hatchery-reared seed are used for enhancement. Saito (1984) reports recapture rates of 5–10 percent for hatchery seed and 20–25 percent for natural seed. Research continues into rearing methods, including hybidization and artificial diets for faster seed growth, and techniques for intermediate culture and release (Saito, 1984; Uki, 1984).

The enthusiasm for seeding in Japan and a steep decline in abalone landings led to a series of seeding studies by biologists from the University of California and the California Department of Fish and Game (reviewed by Tegner and Butler, 1989). Large-scale experiments were conducted with two species (*Haliotis rufescens* and *H. fulgens*) on both island and mainland sites. In each case, the estimated 1- or 2-year survival rate was 2.8 percent or less, unacceptably low for species that require 10–15 years to enter the commercial fishery. Seed sizes ranged from 10 to 80 mm but there was no evidence that survivorship increased with seed size. Estimations of survival rates were based on censuses of planting sites and their immediate surroundings; they do not take into account possible larger scale migrations because of the problems of sampling rare, cryptic abalones. Shell recoveries suggested that mortality related to the stresses of the seeding process was not the major cause of the poor survival; in one closely monitored experiment, half of the shells recovered exhibited growth up to 40 mm before death (Tegner and Butler, 1985). Laboratory studies found differences in behavior and habitat selection between hatchery-reared abalones and natives of the same size classes. These behavioral differences may be responsible for the poor survival of outplants; significantly more cultured than native animals were consumed when predators were added to the laboratory studies (Schiel and Welden, 1987; Tegner and Butler, 1989).

Ebert and Ebert (1988) recently designed an abalone seeding module which acts as a temporary shelter, allowing for acclimation to the natural environment before the seed are released. This approach also has the advantage of greatly reducing the effort required to plant seed, although the results of a predator encounter of such a dense concentration of prey could negate this. The long term effects on seed survival are not known.

Seeding studies have also been conducted with a variety of bivalves, notably clams and oysters. Commercial-scale culture techniques have been developed for important species, but economics dictate that juveniles must be outplanted for growth to market size, and adequate survival is a major problem (McHugh, 1981; Castagna, 1983). High mortality has been repeatedly observed within a very short time for seed clams planted without protection from predators, e.g., Craig et al. (1988) report 100 percent mortality within 6 months of *Mercenaria mercenaria* planted in unprotected trays, whereas survival was high in trays protected with gravel and a mesh covering. Techniques to increase clam seed survival include larger seed size, smaller mesh size, baffles to minimize wave disturbance, predator fences, crab traps, and poisoned bait for predators; combinations of various protective devices are more effective than any device alone (Kraeuter and Castagna, 1985a, b). Similar results have been reported for giant clams in the tropics: Small (10–20 mm) seed placed in unprotected trays on reefs rapidly suffer 100 percent mortality from predation, but survival rates were reasonable in sea floor cages (Munro, 1989). Finally, scallops and oysters have been successfully grown in trays, rafts, or nets in the water column, or in protected plots on the bottom (Castagna, 1983).

The queen conch, *Strombus gigas*, has been harvested since prehistoric times in the Caribbean and remains the area's second most valuable fishery (Berg and Olsen, 1989; Hahn, 1989a). However, the fishery is in serious danger of overharvest and has been placed in the IUCN Invertebrate Red Data Book as a "commercially threatened" species. The seeding of hatchery-reared juveniles was proposed in 1976 as a means to rehabilitate depleted stocks, and the appropriate technology has been developing ever since. While culture of larvae (from wild-collected egg cases) and juvenile growout are feasible, mortality after seeding is very high, sometimes 100 percent. After a series of experiments, Appeldoorn and Ballantine (1983) estimated that only 0.1 percent of seeded 6-month-old juveniles (~ 60 mm) would survive to enter the fishery at an age of 2.5 years. Susceptibility to predation apparently decreases with increasing seed size (Iverson et al., 1986), but seeding with large animals is not economically feasible. Appeldoorn and Ballantine (1983) conclude that seeding of unprotected small conchs does not appear to be a practical way to support a fishery and urge strong fishery management measures to restore the stocks. Once strong management measures are in place, it may be possible to use seeding to build up brood stocks in depleted areas.

The top shell, *Trochus niloticus*, is the most economically important gastropod in the tropical Pacific (Nash, 1988; Hahn, 1989b). The meat is eaten and the shell is exported for the production of mother-of-pearl buttons. Sedentary in habit and found in easily accessible locations, top shell has been overfished virtually everywhere there is a commercial fishery. *Trochus niloticus* is an excellent species for culture because of its year-round spawning which is spontaneous on a lunar cycle, lecithotropic eggs, the short (3–4 day) pelagic period of the larvae, and feeding by juveniles and adults on the algae which grow naturally in outdoor tanks.

The only reported top shell seeding

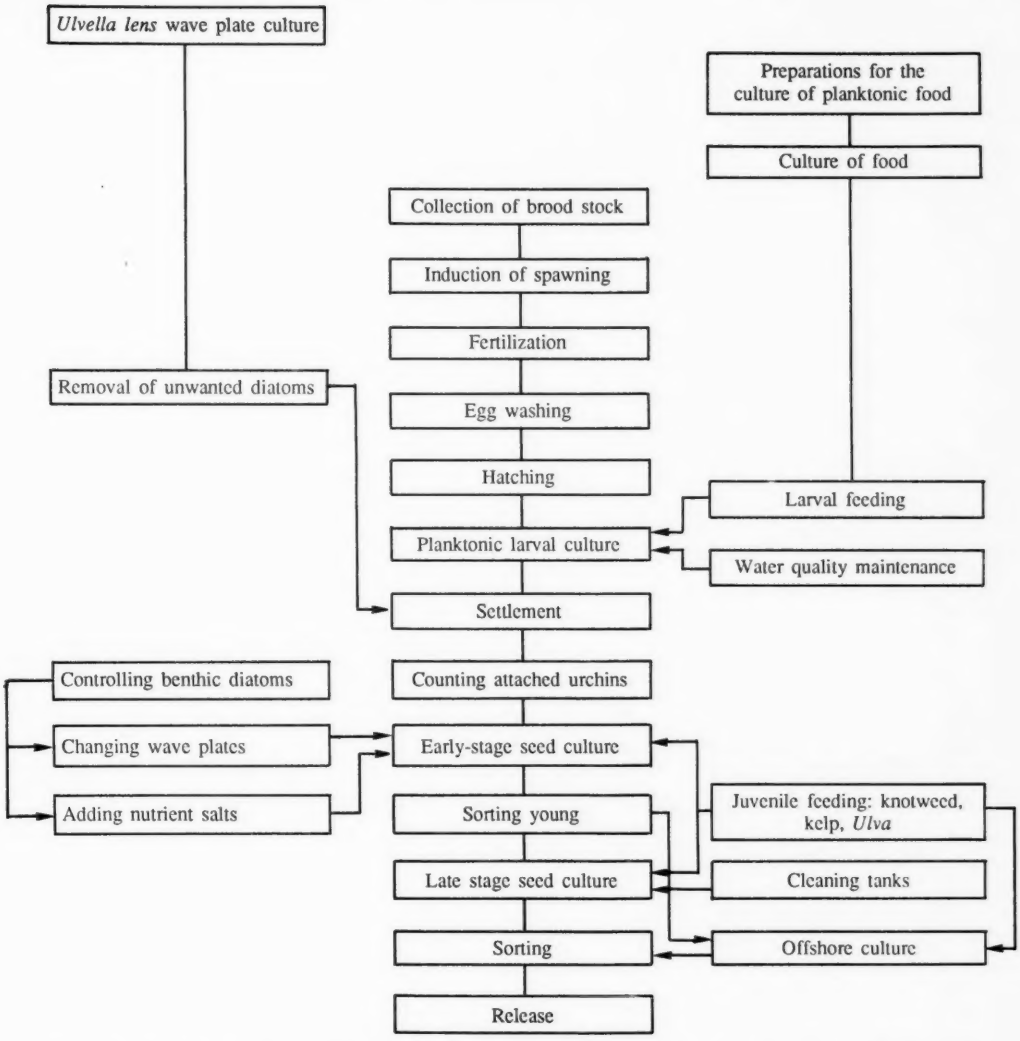

Figure 6.—Steps in the laboratory culture of *Strongylocentrotus intermedius* seed as practiced by the Hokkaido Institute of Mariculture (Saito et al., 1985; Saito, 1987).

experiment was conducted in Palau. In this test, almost total mortality was observed within a couple of days of outplanting; only crushed shell remnants were found[6]. Hahn (1989b) stresses that studies of sources of mortality, microhabitat use, and movement of juvenile top shell should be carried out before large-scale seeding experiments are conducted. Similarly, Nash (1988) suggests that stock enhancement through seeding of hatchery-reared *Trochus* may only be successful if areas of low juvenile mortality are identified.

[6]G. Heslinga. Personal commun. cited in Nash (1988).

Sea Urchin Seeding in Japan

Artificial culture of sea urchins began in Yamaguchi Prefecture in 1968, and Japan produced a total of about 3.5 million cultured seed in 1984. Techniques used to rear *S. intermedius* at the Hokkaido Institute of Mariculture (Fig. 6) have been de-

Figure 7.—Hokkaido Institute of Mariculture abalone hatchery in Shikabe to be converted into a sea urchin hatchery. A and B, tanks containing racks of wave plates; C and D, closeups of wave plates covered with juvenile sea urchins. Photographs taken by Christopher Toole, 1987.

tailed (Saito et al., 1985; Saito, 1987). Many of the techniques appear to have been adapted from abalone culture; in fact, the Institute is converting an abalone hatchery at Shikabe, Hokkaido, to a sea urchin hatchery[7]. Toole[7] visited this laboratory in the spring of 1987 and reports that the sea urchin hatchery is slated to produce 5 million 5 mm seed a year.

Briefly, procedures followed in Hokkaido (Fig. 6; Saito et al., 1985; Saito, 1987) allow females to spawn naturally, releasing eggs into a round 10 L tank. Sperm collected from several males is mixed and used for fertilization. The zygotes are washed at least five times at 30-minute intervals and the fertilization rate assessed. The tanks are then left undisturbed until the larvae hatch at about 20 hours after fertilization. Larvae are transferred to 600 L larval culture tanks at 3 days and feeding is begun. The suitable temperature range is 15°–21°C. For larvae cultured at 18°C and fed a diet of *Chaetoceros gracilis*, metamorphosis and settlement begin on the 16th day after transfer to the larval tanks. Wave plates which have been coverd with a culture of *Ulvella lens*, a species of disk-shaped Chlorophyta, are installed in 5 m tanks to act as settlement substrates, and the water and swimming larvae are transferred (Fig. 7). Settlement of 70–80 percent of the larvae occurs within 3–4 hours, and the water can be exchanged within 24 hours. Toole[7] reports about 60 percent survival to metamorphosis. Seed up to a test diameter of 3–4 mm consume benthic diatoms on the wave plates. Once that size is attained, soft seaweed fronds (e.g., *Ulva*) are placed on top of the wave plates for food (Saito et al., 1985; Saito, 1987).

When the cultured seed reach a size of about 5 mm, they are placed into small mesh cages for intermediate culture in tanks on land or suspended in the sea, as is done with seed settled on collectors. Kelp or knotweed is provided as food. It is desirable to adjust sea urchin density and cage mesh size as the seed grow. Release size is 15 mm or larger. With fertilization in September-October and intermediate culture offshore, sea urchins reach release size the following autumn. In shore-based facilities where the water

[7]C. Toole, Sea Grant Marine Advisory Program, Eureka, CA 95501. Personal commun., 1988.

is heated during the winter, the seed are large enough to be released in 5 months (Saito et al., 1985; Saito, 1987). Fishermen broadcast the seed over the fishing ground from the surface[7].

Omi (1987) reported the results of seeding experiments using cultured *S. intermedius* in Hokkaido. In each of two tests, 40,000 seed were released into areas measuring 20 × 50 m in water depths of 3 m. Seed were spread uniformly over release sites by divers and from boats. Survival rates were assessed by divers with m^2 sampling frames. Released sea urchins were generally distinguished from natives by test diameter. The survival rate after 622 days for the 1983 release group was 38.7 percent, and 92 percent of these had achieved the minimum legal size of 40 mm. For the 1984 group, the survival rate after 597 days was 22.6 percent, and 91 percent were of fishable size. Other studies showed variation in survival rates between 10 and 40 percent, as well as in growth rates, in different areas. The seed spawning season was the same as that of the parent stock, which varies among different areas of Hokkaido, regardless of where they were planted. Agatsuma and Momma (1988) compared the growth of cultured and native seed. They found that the introduced seed grew faster than the native seed during the first 14 months, but that the cultured seed growth rate decreased thereafter and was lower than that of the native stock after 3 years.

Omi (1987) estimated the economic benefits of sea urchin seeding in a 10,000 m^2 area at a site which supported excellent growth and survival rates. Income was calculated as the number of seed surviving (40 percent) times the catch rate times the gonad weight times the unit price:

$$1{,}797{,}120 \text{ Yen} = 16{,}000 \text{ seed} \times 0.9 \times 7.8 \text{ g/urchin} \times 16 \text{ Yen/g}.$$

Expenditures were calculated as the cost of the seed (produced by the Hokkaido Institute of Mariculture) plus labor costs for the release operations plus transport costs of the seed:

$$1{,}040{,}000 \text{ Yen} = 40{,}000 \text{ urchins} \times 25 \text{ Yen} + 20{,}000 \text{ Yen} + 20{,}000 \text{ Yen}$$

Profit was calculated as income minus expenditures divided by the number of fishing seasons:

$$378{,}560 \text{ Yen} = (1{,}797{,}120 \text{ Yen} - 1{,}040{,}000 \text{ Yen}) \div 2$$

This estimate suggests a 36 percent return on investment. If the sea urchins are allowed to grow for another year (assuming no further decline in numbers between years 2 and 3), the average gonad weight per sea urchin rises to 12 g, and the profit rises to 574,933 Yen for the same expenditures. Omi (1987) does not appear to have accounted for the capital investment in the hatchery in these calculations.

Studies of *Pseudocentrotus depressus* in Yamaguchi Prefecture indicate that sea urchin seed survival is better on gravel beds (65–76 percent) than on rocky substrates (38 percent), even though food is much more (3–6 times) available on the rocky substrate (Takagi, 1986). Hybrids of *P. depressus* with *Hemicentrotus pulcherrimus* developed larger gonads with better color than *H. pulcherrimus*, the favored species.

Culture of Strongylocentrotus franciscanus *in California*

The importance of sea urchins as experimental animals for cell biology has led to extensive studies of their larval development and culture. Hinegardner (1969) developed the basic methodology for culture of west coast species on a laboratory scale, and various refinements have been published (Hinegardner, 1975; Hinegardner and Rocha Tuzzi, 1981; Leahy, 1986). Leahy et al. (1978, 1981) described a laboratory system for long-term maintenance of gravid sea urchins and discovered that ripe animals could be found in the wild throughout the year by collecting from deep-water populations with good food supplies. Because of their importance to cell biologists, much of the focus has been on *S. purpuratus* and the white sea urchin, *Lytechinus pictus*, but with minor modifications, the same procedures work with *S. franciscanus* (Hinegardner and Rocha Tuzzi, 1981). Thus, culture on a small scale is both feasible and practiced. It may be possible to further reduce the larval period by culture at higher temperature. The key to production on the scale necessary for seeding, however, will be the successful adaptation of mass culture techniques such as those used for abalones and sea urchins in Japan (McCormick and Hahn, 1983; Saito et al., 1985).

McCormick and Hahn (1983) studied abalone aquaculture at prefectural fish farming centers in Japan and estimated what it would cost to establish a Japanese-style abalone hatchery in California capable of producing 20 million juvenile (20 mm) abalones annually. Conversion of a Hokkaido hatchery from abalones to sea urchins clearly indicates that the two groups require similar facilities and treatment; the major differences are that sea urchin larvae are planktonic for a longer period of time and require feeding. Thus, cost estimates for setting up an abalone hatchery are an appropriate base for sea urchins; phytoplankton culturing capabilities and extra tanks for larval rearing would be additional.

McCormick and Hahn (1983) estimated capital costs for land (1 hectare, central California coast), buildings, tanks, culture plates, plate racks, filters, two vehicles, emergency generator, water pumps, plumbing, air pumps, water heater, UV sterilizer, brood stock, and cleaning equipment at $576,200. Operational costs including wages, utilities, vehicle upkeep, feed, telephone, filter upkeep, and generator upkeep were estimated to be $205,100 a year. Summing these two with startup salaries and debt service, the funding required to produce the first 1 million abalones would be $1,155,857 (McCormick and Hahn, 1983). This estimate does not include additional expenses such as financial and legal services, operating permits, taxes, depreciation, or replacement costs. Given the huge increases in the price of coastal land, inflationary increases on goods and salaries since 1983, and the extra costs involved

with culturing sea urchins, the costs of establishing a sea urchin hatchery of similar size in 1989 may be several hundred thousand dollars more.

Enhancement of Fishable Stocks Limited by Survival of Newly Settled to Intermediate-sized Animals

Habitat Improvement

Mottet (1976a, b, 1981) has reviewed the extensive efforts of the Japanese to enhance sea urchin stocks through habitat improvements. The use of rocks to improve the substrate for sea urchins dates to 1912 in Fukui Prefecture and has spread through much of the country. In areas of flat substrate, the addition of rocks may increase the yield of many marine species, especially kelp and sea urchins, by providing algal attachment sites, shelter for the sea urchins, and aid in drift entrapment. This is accomplished either by importing rocks or reef blasting. Generally rocks of 40–50 kg are placed in a layer 1–2 rocks deep with plenty of space between rocks. It was estimated that it takes 50 rocks weighing 40–50 kg each to increase the yield of gonads by 1 kg. At this rate, it took about 3 years for the operation to pay for itself (Mottet, 1976b).

Historically, Japanese habitat improvement projects were funded by fisheries cooperatives and local governments (Mottet, 1981). The national government began providing funding in the 1930's, and the level was greatly intensified in the mid 1970's. With the national government paying for 50–70 percent of the costs of selected projects, habitat improvement efforts became much more complex and capital intensive.

Habitat improvement projects spread to soft substrates (Mottet, 1981). In the simplest procedure, rocks are piled to a height of 0.4–0.6 m to provide habitat for kelp and sea urchins. In areas of high water movement where the rocks would not be stable, they may be piled in enclosures. The most common structure is a "futon" (mattress) cage measuring 4 m long by 1.2 m wide by 0.4–0.6 m high, and made of synthetic fiber net or coated mesh steel (Fig. 8). These are placed by cranes into areas where strong currents ensure circulation through the rocks. Sometimes the cages are set on mats to prevent them from sinking into the sediments. As of 1981, futon cages were the most widely used sea urchin enhancement device, particularly in northern Japan where they were being placed by the thousands in many locations. Mottet (1981) cites one example where 10,000 futon cages were installed in a 27-hectare area in Hokkaido. Other kinds of rock cages, ranging from bamboo baskets to steel or concrete cribs, are also employed.

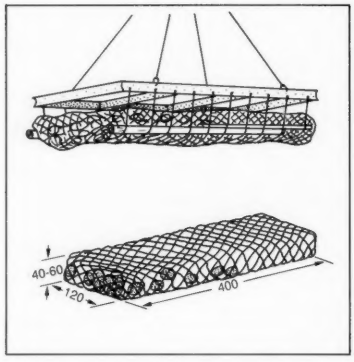

Figure 8.—Futon cages, or mesh bags of rocks of 20–50 cm diameter, are used to create sea urchin habitat in areas of soft sediments. As these cages weigh 2.9–4.4 t, a crane and a sling supported by a steel frame and logs are used to place the cages into position. Dimensions are in centimeters (Mottet, 1981).

Mottet (1981) also described a variety of additional techniques which, alone or in combination with other habitat improvement methods, are designed to enhance fishable stocks of grazers. Large concrete "substrate" blocks provide horizontal surfaces for the seaweed attachment and crevice spaces suitable for sea urchins and abalones. As these are often used in areas with strong water motion, they may weigh a ton or more but are no higher than 1 m. Large, concrete breakwater blocks, designed to dissipate wave action, are good for trapping drift or containing rock piles. If high water movement leads to problems with kelp abrasion on the rock piles or substrate blocks, elevated frames may be installed as supports for stiff, plastic mesh pipe seeded with algae. The fastest way to increase kelp biomass is longline culture of *Laminaria*. Typically such lines are 45–50 m long and buoyed above the bottom; usually a number of lines are employed and spaced 3–8 m apart. A 50 m longline can produce nearly 1.5 t of harvestable kelp in one season, while providing drift food for grazers and seeding nearby reefs. Many large-scale development projects are designed to maximize both kelp and sea urchin production, e.g., sea urchin habitats may be located in such a way that drift entrapment is efficient but sand buffer zones protect benthic kelps from direct grazing.

Finally, one project from Iwate Prefecture suggests perhaps the ultimate in habitat improvement efforts (Mottet, 1981; Noma, 1983). In Japan, many edible seaweeds and grazers do not grow well above the mean spring low tide levels because of dessication in the summer and freezing in winter, but these same species prosper in natural channels which cross rocky benches. In this project, a total of 92 channels (~ 100 m long × 4 m wide × 0.6 m deep) were dug into rocky intertidal platforms at 8 sites along 5 km of coastline. The channels were designed in such a way that waves passing into the entrances are funneled up and over sills which then act as one way valves. Thus wave energy moves the water shoreward until it reaches an excurrent drainage channel slightly deeper than the culture channels, and water circulation is ensured. The design achieved a water flow velocity of 0.15 m/second with waves of 0.2 m height (Noma, 1983). Substrate blocks were added to the culture channels to maximize the surface available for kelp attachment and provide suitable habitat for grazers. Ten of these channels, with a combined length of 1,200 m, were completed in 1975 at a cost

$326,087. The average annual harvest of kelp, abalones, and sea urchins combined in the initial results was worth $37,097, suggesting a pay-back period of about 9 years. These observations suggested that the most profitable return would be from the combined culture of kelp and sea urchins. *Laminaria* seeded into the channels in December had grown enough to provide a good source of sea urchin food by May. Sea urchins were collected from areas of inadequate food supply and transplanted into the channels; in a few months of fattening, the gonads increased from less than 7 percent to 25 percent of the total body weight. The relative value of these two commodities and an experiment varying sea urchin numbers were used to determine optimal stocking densities; an intermediate level of sea urchins allowed maximal gonad development of two crops of sea urchins each year with an annual profit of $5,217 per channel (Mottet, 1981). Noma (1983) compared the productivity of the rocky bench before and after the channels were built; profit in 1980 was 258 percent of the 4-year average before construction.

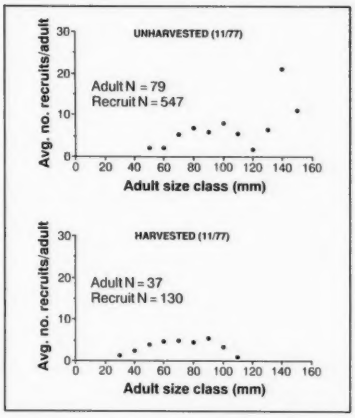

Figure 9.—Average number of recruits per adult versus adult size class in spine canopy associations of *Strongylocentrotus franciscanus* populations on Santa Barbara Island, Nov. 1977.

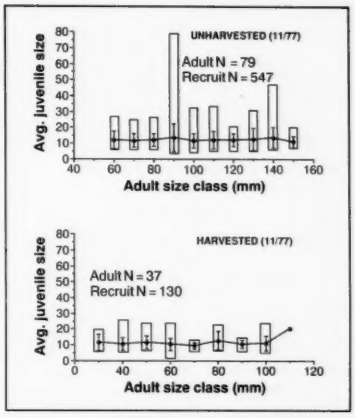

Figure 10.—Average juvenile red sea urchin size vs. adult size class in spine canopy associations of *Strongylocentrotus franciscanus* populations on Santa Barbara Island, Nov. 1977. The error bars represent ± one standard deviation and the boxes indicate the range of the data.

Protection of Juveniles by the Red Sea Urchin Spine Canopy Association

Two papers (Breen et al., 1985; Sloan et al., 1987) have recently explored the biology of the *S. franciscanus* spine canopy association in British Columbia, where the minimum size limit for red sea urchins is 100 mm. Field data showed that the innermost, under-the-test juveniles were significantly smaller than more distal but still under-the-spine-canopy young, and that juveniles not underneath adults, whether clustering nearby or not associated with an adult, were significantly larger than juveniles under the spine canopy. This size-related distribution pattern of young animals suggests that the smaller size limit in California has important implications for the survival of recruits.

To look at the role of different sized adults as shelter providers, individual "associations" were sampled by collecting adults and any associated juveniles and placing each association in a separate bag. Data were collected on Santa Barbara Island, a site of consistently good red sea urchin recruitment[2], in 1977 and 1978. In 1977 the associations in an area where the size-frequency distribution indicated recent fishing were compared with a nearby site where the abundance of larger animals suggested that the site had not been harvested for some time, if at all. At that time the fishery was generally taking animals larger than 90 mm. At the unharvested site, there was a significant increase in the average number of juveniles sheltered with increasing adult test diameter (r^2 = 0.398, P = 0.037). There was no such trend at the harvested site where juveniles were found under shelter providers as small as 30 mm, 20 mm smaller than in the unharvested area (Fig. 9).

Despite the sites being only about 200 m apart, the average number of recruits per adult in the harvested area was only about half that in the unharvested area, 3.5 vs. 6.9. The average size of juveniles under adults in the unharvested area was 12.20 mm and 10.98 mm in the harvested site; while small, this difference was significant (t test, P = 0.005). There was no increase in average size of juveniles with increasing adult size, probably because most of the juveniles resulted from a single settlement episode (Fig. 10). In the unharvested site, 74 percent of the recruits were found under shelter providers 90 mm and larger (Fig. 11). For the harvested population, 29 percent of the juveniles were under animals 90 mm and larger, and 62 percent were under shelter providers 60 mm and larger. Thus, faced with few large sea urchins under which to shelter, juveniles were associating with smaller shelter providers with correspondingly smaller spine canopies and therefore less protection from predators. In addition to there being less space under small spine canopies, red sea urchins smaller than 90 mm have not yet reached the size offering a partial refuge from predation (Tegner and Levin, 1983). This suggests that the associations based on shelter providers less than 90 mm have a lower

probability of survival regardless of fishing.

Samples from the same area of Santa Barbara Island collected in May 1978 contained adults up to 128 mm (data not shown). The average number of juveniles per shelter provider was 5.0 and there was a positive relationship between the size of the adult and the number of recruits sheltered (r^2 = 0.867, P = 0.0001). Again there was no increase in the average size of juveniles with increasing adult size. Fully 84 percent of the sheltered individuals were under adults of fishable size. Sheephead are attracted to divers and frequently feed on juveniles exposed upon removal of the adults. In a series of adult removal trials on San Clemente Island, some recruits were rapidly eaten while others managed to crawl out of sight to safety. The fate of juvenile sea urchins exposed by fishing depends in part on how much cover, e.g., other shelter-providing urchins, substrate rugosity, or foliose algae, is available (Tegner and Dayton, 1981).

A number of smaller data sets collected in the late 1970's were examined for the relationship between the average number of sheltered recruits and adult size class. Tegner and Barry[2] lumped samples from San Clemente Island and from Santa Rosa and San Miguel Islands to consider the effects of two different population structures on juvenile sheltering. The relationship seems most likely to be positive when the average number of recruits per adult is high. This degree of variability is not surprising given the gregarious behavior of juveniles (Breen et al., 1985) and variability in recruitment rates and habitat structure.

However variable, the relationship seems sufficiently compelling that these observations should be repeated, especially in southern California where predation pressure is higher, to determine the effects of a decade of intense fishing pressure. Ideally, recruitment and spine canopy associations should be assessed in both fished and nearby areas closed to fishing to evaluate the relative effects of brood stock reduction and loss of large spine canopies. If, as suggested by the results of Tegner and Dayton (1977), survival of recruits is depressed in fished areas, provisions should be made to leave some portion of fishable animals behind to ensure future regrowth of stocks. It is likely that a maximum size limit of 125 mm is not appropriate in southern California; there are simply too few animals that large left. Size-frequency data suggest that this may be a more useful approach in northern California[8], however. If there are too few animals 125 mm or larger to provide spine canopy shelters, alternatives are to institute a smaller maximum size limit, or to require fishermen to leave some minimum density of animals behind, a much more difficult regulation to enforce.

Enhancement of Fishable Stocks Limited by Food Availability

Transplantation to Areas of Better Food Supplies

Mottet (1976a, b) reviewed the efforts of Japanese fishing cooperatives to increase gonad development by transplanting sea urchins from areas of high density but poor food supply to areas with rich seaweed populations. Although the animals may be out of the water for 24–26 hours, there is only a 1–2 percent mortality rate associated with transfer. Transplantation is generally done just before the sea urchins begin the period of rapid gonad growth. In Hokkaido, if food conditions are good in the fall, sea urchins can be transplanted then for harvest in the spring. Sea urchins transplanted in the spring are ready for harvest about July. Transplanted animals exhibit gonad weights which are 4–5 times those of nontransplanted controls and similar to the yields of animals originating in the high food areas. A second objective of transplanting is to move sea urchins to high food areas which are also workable during winter periods of bad weather and high sea urchin prices. The economic return of this method of enhancing fishable stocks is suggested by the magnitude of the operation; in some localities, up to 20 t of sea urchins had been transplanted by 1969 to improve gonad yield. Takagi (1986) reports cases where the fishery may depend exclusively on annual transplants.

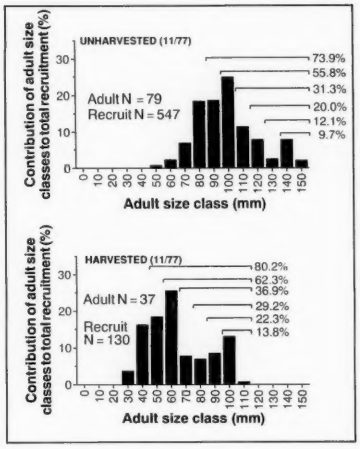

Figure 11.—Contribution in percent of each adult size class to the total sheltering of recruits in spine canopy associations of *Strongylocentrotus franciscanus* populations on Santa Barbara Island, Nov. 1977. The cumulative percent beginning with the largest adults is indicated.

Implications for *S. franciscanus*. While food-limited animals can be found in many areas, large red sea urchins are subject to coelomic collapse if they are out of the water for more than a few minutes. Once air gets into the coelom, survival is uncertain. Kelco[9] has found it possible to minimize transport mortality by hanging sea urchins to be moved below the surface in large mesh bags until it is time to actually move the boat.

Reforestation of Areas with Poor Food Supplies

As in California, some rocky bot-

[8]P. Kalvass, Calif. Dep. Fish Game, 19160 S. Harbor Drive, Fort Bragg, CA 95437. Personal commun., 1989.

[9]M. Otjens, Kelco, P.O. Box 13216, San Diego, CA 92113. Personal commun., 1989.

tom areas on the northeastern coast of Honshu, the largest island in Japan, are often observed to be nearly devoid of large, foliose plants; encrusting coralline algae cover the bottom[10]. These barren grounds, or isoyake in Japanese, are often characterized by unfishable (small and/or starving) populations of sea urchins and abalones which prevent the regeneration of kelp populations. A 5-year experiment demonstrated that it is possible to reestablish a kelp forest and productive fishery without killing the grazers. The experiment was conducted in a 3-hectare V-shaped bay on Enoshima Island which contained dense populations of urchins (*S. nudus*) and abalones (*H. discus hannai*). To provide food for the grazers, *Laminaria japonica* was cultured on longlines arranged in a grid with 2–3 m spacing and buoyed off the bottom. This proven methodology had already been worked out for the production of edible seaweed. In 1972, longlines totaling 3,825 m produced 33.3 t of kelp, and in 1973, 4,200 m produced 41.5 t. As a result of the increased availability of algal drift, the sea urchin gonads were well developed and the annual increase in abalone body weight was 4 times that of animals in control areas without supplemental feeding. In 1973, over 3.4 t of sea urchins and 3.2 t of abalones were harvested. The reduction in herbivore numbers and the release of spores by the cultured *Laminaria* led to a large natural bloom of algae in the spring of 1974. It was estimated that the standing crop of suitable food for the sea urchins and abalones was more than 100 t, eliminating the need for further longline culture. Kito et al.[10] believed that this amount of seaweed was enough for a gross annual production of 6.6 t of urchins and 3.1 t of abalones.

Implications for California: Kelp culture to improve fishable stocks of red sea urchins is certainly a possibility in California, but several factors must be considered. First, the experiment at Enoshima Island described above (and much of the longline mariculture in Japan) was conducted in a relatively protected bay. Most of the California coast is much more exposed. Second, the kelp farming industry, still in its infancy in California, is primarily involved with research and development, suggesting that commercial longline production may be prohibitively expensive. A private company in Goleta has studied *Macrocystis* test farms (Neushul and Harger, 1985), and is currently operating longline farms for a study of marine farm engineering that deals with storm resistance. Neushul[11] estimated that it would cost about $600 to produce a 50-foot (15.2 m) longline seeded with macroalgae. This estimate does not include the cost of the line, floats, shackles, anchors, or shipping. In Japan, longline cultures are produced by the fishing cooperatives.

The Problem of Competition

Widespread areas within southern California are reported to have undergone large increases in the number of purple sea urchins in recent years, and these animals can also cause overgrazing. There are several, nonexclusive, potential explanations for this apparent increase. First, red and purple sea urchins have similar food (Leighton, 1966; Vadas, 1977) and habitat (Schroeter, 1978) preferences. Schroeter (1978) reported that red sea urchins exclude the shorter-spined purple sea urchins from the most desirable habitats by spine fencing. The harvesting of thousands of tons of *S. franciscanus* may thus represent a release from competition for *S. purpuratus*. Furthermore, the large red sea urchin fishery has undoubtably reduced larval production in this species; there has been no comparable reduction for purple sea urchins so these animals may be recruiting at a higher rate. Finally, the 1982–1984 El Niño led to a large pulse in sea urchin recruitment on the northern Channel Islands, a pulse that was larger for purple than for red sea urchins[2]. Whatever the reason for this reported increase, large populations of *S. purpuratus* appear to be controlling algal food supplies in some areas, notably on the northern Channel Islands[12], and this situation will inhibit the regeneration of red sea urchin stocks.

Purple sea urchins are similar in size to the species harvested in Japan so there should be no acceptance problem for the export market. However, their smaller size makes harvesting and processing prohibitively expensive[13]. Less expensive harvesting methods such as dredging or air pumps or mechanical processing may make fishing for purple urchins financially feasible. Alternate uses, such as for animal feed or soil supplements, are also under investigation[14].

The Feedlot Approach

Kelco, a San Diego-based kelp harvesting firm, has been experimenting with enclosing and feeding red sea urchins in barren areas of the Point Loma kelp forest as part of their kelp management activities[9]. Their objective is to reduce grazing pressure sufficiently that kelp will grow in formerly productive areas. After trying several different net configurations, their current model consists of nylon cargo net with 3.5 × 4.1 cm mesh. The netting is cut to dimensions of 0.3–0.6 m by the length of the enclosure. Lead core line (0.64 cm diameter) is threaded through the bottom of the net to act as a weight, and 0.95 cm polypropylene line is threaded through the top of the net to provide flotation. The leadline is anchored to the substrate using mushroom-head, nylon cement anchors and

[10]Kito, H., S. Kikuchi, and N. Uki. Seaweed as nutrition for marine life: Technology for artificial marine forests. Pap. pres. at Int. Symp. Coastal Mar. Life, Western Wash. Univ., Oct. 1979, p 55–66.

[11]M. Neushul, Neushul Maricult. Inc., 475 Kellog Way, Goleta, CA 93117. Personal commun., 1988.

[12]G. Davis, Channel Isl. Natl. Park, 1901 Spinnaker Dr., Ventura, CA 93001; R. McPeak, Kelco, P.O. Box 13216, San Diego, CA 92113; B. Steele (commercial sea urchin fisherman), P.O. Box 91609, Santa Barbara, CA 93190. Personal commun., 1988–89.

[13]D. Rudie, Catalina Offshore Products, 4537 Mt. Henry Pl., San Diego, CA 92117. Personal commun., 1989.

[14]A. Chadwick (commercial sea urchin tender), Box 3033, California Valley, CA 93453. Personal commun., 1989.

nylon cable ties. Materials cost for this enclosure is estimated at about $0.50 per linear foot (30.5 cm). Observations suggest that the sea urchins are reluctant to cross the net which is kept in motion by surge; the few escapes were by animals that managed to get under the net.

Kelco has tried several pens ranging in circumference up to 130 m, as well as linear barrier fences to prevent sea urchins from entering areas where kelp was recruiting. About 2,000 red sea urchins per pen were transplanted with a very low mortality rate. The sea urchins were fed chopped *Macrocystis* taken from the surface canopy about once a week, and gonad development was rapid. Two months after these barren ground animals were penned, 100 kg of sea urchins were harvested and found to have good quality roe. Kelco forsees using this technique to reduce grazing pressure during the optimal spring season for kelp recruitment and to control sea urchin fronts[9].

This technique appears to be low cost and have considerable promise for short-term enhancement of fishable red sea urchin stocks where sea urchin populations are limited by food availability. While it is not yet clear how long these nets will last, Kelco's data suggest that each net could produce several "crops" per year. Furthermore, the environmental results could be long term; where sea urchin densities are reduced, kelp is likely to recruit and end the problem of food limitation.

L. Romina[15] reports that Japanese brokers are encouraging Mexican sea urchin fishermen to establish pens for feeding red sea urchins to increase their gonad yield, in a manner analogous to the feedlot approach widely used for cattle. This method, now apparently practiced in Japan, involves terrestrial forage such as alfalfa. We do know that the Japanese have experimented with knotweed and other easily obtained terrestrial plants in intermediate culture of seed during periods when algae are not readily available. Knotweed leaves supported faster growth than kelp for sea urchins up to 15 mm; for larger animals, the two feeds produced similar results (Department of Mariculture, Hokkaido Central Fisheries Experimental Station, 1984).

Nitrogen is a critical element in the survival and growth of all organisms due to its central role in metabolism, cell structure, and genetic coding. Plants experience shortages of inorganic nitrogen; herbivores encounter shortages of organic nitrogen, often in the presence of abundant calories (Mattson, 1980). Russell-Hunter (1970) calculated that all animals (except ruminants) have adult nutritional requirements for protein amounting to about 16.5 percent dry weight of their diet. This corresponds to a diet with a C/N ratio below 17:1. The C/N ratio of *Macrocystis* varies seasonally following ambient nitrate concentration (which is inversely related to temperature and negligible above 16°C (Jackson, 1977)), and may vary from less than 10:1 to greater than 40:1 (Wheeler and North, 1981).

While the role of nitrogen limitation of kelp forest herbivores is poorly understood, there are indications that nitrogen strongly affects both growth and reproduction. Ogino and Kato (1964) found a strong positive correlation between growth of abalones and the amount of protein in artificial diets. Shifts of feeding preference toward more protein-rich foods have been observed; sea urchins selected bryozoan-encrusted kelp (Bonsdorff and Vahl, 1982) or artificial food made with animal protein (McClintock et al., 1982). Evidence for the effect of nitrogen limitation on reproduction comes from the work of Leahy et al. (1981) who compared oogenesis in shallow (4–6 m) water populations of *S. purpuratus* with that of animals collected from a deep (15–21 m) water, subthermocline habitat where temperatures are more favorable for nitrate availability. The shallow population produced few gametes from August through November, when nitrate concentrations tend to be low (Wheeler and North, 1981), whereas the deep-water population was equally fertile all year round. D. Rudie[13] reports that red sea urchin roe yields were higher during the 1988–89 period of colder than normal temperatures. While more research is needed, these observations suggest that increasing the nitrogen content of the food, whether by collecting kelp from below thermocline depths, fertilizing warm water kelps, or using terrestrial plants with a high nitrogen content, would increase growth and gonad development rates.

Structure of the Japanese Fishing Industry and Implications for Enhancement of Red Sea Urchin Stocks in California

Marine fishes in the United States are traditionally common property resources. An individual fisherman has little incentive to conserve or enhance the resource because of the likelihood that someone else will reap the benefits of his actions. In contrast, local control of the fishing grounds was established in Japan during the Tokugawa feudal period (1603–1867) (Mottet, 1980; Sato, 1987). These rights were codified, democratized, and redistributed to assure greater control by the working fishermen during the 20th century. A fishery right (nearshore fisheries are managed by the fishery rights system) is the exclusive right to conduct certain types of fishing operations in a specific area under permit from the prefectural governor. A 1948 law required fishermen to form cooperatives to receive priority in obtaining fixed net (which allows fishing by placing fishing equipment in a designated area) and common (which allows joint use of a designated area for fishery purposes) fishery rights and allowed cooperatives to engage in a variety of activities ancillary to fishing. Now the common fishery right is only granted to fishermen's associations composed of fishermen possessing certain qualifications; there are some 3,000 fisheries cooperatives in Japan eligible for common fishing rights (Sato, 1987). Many fishery regulations are instituted at the prefectural level, but fisheries cooperatives often further restrict access, e.g., limiting

[15]L. Romina, Inst. Nac. Pesca, Ensenada, Baja Calif., Mex. Personal commun., 1989.

the number of days and the number of hours per day that a certain fishery is open, gear restrictions, etc., to conserve their stocks (Mottet, 1976a; Takagi, 1986).

While the law does not give fisheries cooperatives priority for demarcated (aquaculture) rights, many governors allow the local cooperatives to administer these rights as well to permit all of the necessary compromises between culture areas and other fishing rights to be made without government involvement. The cooperatives which receive these rights then treat them as income and divide the profits among members. If native stocks and aquacultural sites are fully exploited, new memberships in a cooperative may be all but impossible to obtain. Cooperatives frequently sponsor projects to increase productivity of the fishing grounds for the benefit of all members. These projects commonly include bottom improvements, artificial reef construction, or predator control. Some cooperatives are also very involved in the operation of hatcheries and/or seeding projects (Mottet, 1980).

In addition to control over the fishing grounds, a variety of other institutional factors favor and support enhancement activities. The Japanese have the highest annual per capita fish consumption of any major nation, and they consume one-seventh of the world output of fisheries products (Mottet, 1980). With the increase in fuel prices of recent years, the nearly full exploitation of the world stocks of table-grade species, increasing competition from other countries in high sea fisheries, restrictions or loss of access associated with extended fisheries jurisdictions, and the loss to pollution of some domestic coastal fishing areas, Japan has been forced to improve the productivity of her remaining coastal waters to maintain supplies of valuable species. Insecurity over sources of supply have led to a political consensus which makes it possible for fisheries to receive a disproportionate amount of government aid. For example, the 7-year Coastal Fishery Development Project funded in 1976 provided new government subsidies of $1 billion to increase coastal production. This effort was directed at areas of the continental shelf less than 50 m in depth and included diverse activities such as improving spawning and nursery areas, release of seed and fry, construction of artificial reefs and habitats, wave reducing facilities, bottom improvements, and predator control. As Mottet (1981) summarizes:

"Even with these intense research efforts, the results from the preliminary studies always appear grossly inadequate for justifying the projects. The fact that the projects are still funded probably rests less on biological and economic data than on the political situation which has resulted from the worldwide introduction of 200-mile fishing zones. It seems that Japan is determined to increase its own coastal fisheries production, no matter what the cost, so it will be less susceptible to manipulation by foreign governments."

Other important aspects of the fishing/culture infrastructure include government subsidies through low-interest loans and culture insurance (Mottet, 1980). The fishing cooperatives take care of many business aspects such as marketing, purchasing, financing, and insurance, leaving the fisherman or culturist more time to devote to his primary activity. Finally, Japan has an extensive network of research, education, and extension services. There are fisheries high schools and college programs. Research is supported by every level of government as well as by the cooperatives themselves, and much is heavily subsidized by the national government.

In California, it is possible to obtain some degree of control over nearshore water bottoms. The Fish and Game Commission leases state-owned tidelands for aquaculture. The primary lessees to date have cultured bivalves, but in recent years leases have been given for abalones, a group ecologically similar to sea urchins. The California Fish and Game Code provides that all lawfully cultivated organisms that are described in the application for the lease and produced in the area are owned by the lessee. The lessee has the exclusive right to cultivate and harvest the aquatic organisms in the lease site. Thus, a lease would make it reasonable for a fisherman to invest the time and resources to plant collector-caught or cultured seed, to grow kelp, or to feed hungry animals. Exclusive rights would also provide incentive for a fisherman to follow conservative fishing practices such as leaving behind some minimum density of adult red sea urchins to provide spine canopy protection for recruits.

A major problem with water bottom leases in California may be enforcement; there are simply too few Fish and Game Department wardens to police leases. If fishermen (and processors) were to further follow the Japanese model and to enter into agreement over rights to the local fishing grounds, it may be possible to ensure the dividends of each individual's efforts. As leases are subject to public comment, additional potential obstacles to this approach are other sea urchin fishermen who may feel that their rights are being infringed upon, or other users of kelp forest resources such as recreational fishermen or kelp harvesters. Such considerations underscore the importance of an information campaign and involvement of all concerned with the resource before leases are applied for[16].

Fish and Game Commission water bottom leases do not, however, allow for modification of the bottom[16]. Such habitat improvement approaches as the addition of rock piles or habitat structures would have to go through the same approval process as required for artificial reefs—approval or permits from the U.S. Army Corps of Engineers, California Coastal Commission, State Lands Commission, Department of Fish and Game, and the local Regional Water Quality Control Board. Any potential conflicts with existing sport or commercial fisheries

[16]R. Collins, Calif. Dep. Fish Game, 1416 Ninth Street, Sacramento, CA 95814. Personal commun., 1989.

must be resolved. The importance the Japanese place on locally produced seafood is not apparent in California where esthetic and recreational uses of the nearshore environment often take precedence over mariculture. While artificial reef construction is common and establishes precedent for some types of habitat improvement, major modification of a multiuse resource such as cutting channels in rocky intertidal benches is likely to meet with serious opposition from the Coastal Commission and others.

Discussion

Thus, there are several biological options for enhancing fishable stocks of *Strongylocentrotus franciscanus* which vary widely in cost, the amount of labor required, duration of the results, and effects on current landings. While all these approaches offer some biological potential for success, none has been adequately field tested in California. These options raise questions about who will pay for enhancement, who will do the work and reap the benefits, and whether any of the approaches will be cost effective now or in the future when wild stocks are likely to be smaller.

Enhancement of stocks limited by food availability apears to represent both the highest biological probability of success and the shortest time interval before efforts pay off. The capital investment for nets or pens is likely to be relatively low compared to other approaches to enhancement, but operation will be labor intensive. This approach is basically short term in its effects, although areas where grazing pressure is reduced sufficiently are likely to regenerate kelp populations and improve the conditions for the next generation of sea urchins—assuming that larval supply and/or immigration of the desired species are adequate. Unless purple sea urchin densities are reduced, however, some habitats are unlikely to regenerate. This approach is also clearly affected by the supply of food-limited sea urchins, which may vary considerably among areas. Animals from barren grounds (such as several square kilometers south of the present day Point Loma kelp forest in San Diego) or those living seaward of the kelp zone in central and northern California (e.g., Pearse and Hines, 1979) are obvious candidates. It may also be possible to increase the period of time during which sea urchins from seemingly non food-limited habitats are of fishable quality by increasing the quantity or nitrogen content of their food. This approach is clearly not capable of supporting all California sea urchin fishermen, but it may prove productive for several individuals to establish water-bottom leases and feeding regimes in each area.

It should be noted that the California Department of Fish and Game requires a permit to transplant animals. There is also a question of the legality of penning sea urchins which are a common property resource (in contrast with seeded sea urchins which have been produced by the owner)[16].

Increasing the supply of juvenile sea urchins, whether by collection of seed from settlement plates, release of cultured late-stage larvae, or culture of seed in hatcheries, would seem to be the most efficient way of enhancing fishable stocks in areas where populations are limited by larval supply—if any of these approaches can be shown to work in California. Seeding of hatchery-reared juveniles has been seen as an attractive solution for many species, but as Hahn (1989a) observes, "There is little, if any, evidence that hatchery production has ever had any measurable effect on natural fishery populations of any marine invertebrate." Conversion of an abalone hatchery to sea urchin culture and the data reported by Omi (1987) suggest that managers in Hokkaido are encouraged about the prospects for sea urchin seeding, but until more results are provided, they must be regarded as preliminary. Hatcheries are capital intensive and operational costs are high (McCormick and Hahn, 1983). Collection of settling larvae from the plankton followed by intermediate culture in the sea is much less capital intensive but is subject to the vagaries of current patterns and larval supply (Table 2). Presumably these are the reasons that led to the sea urchin hatchery in Hokkaido.

Tegner and Barry[2] have identified the southeastern Channel Islands, Santa Barbara, and especially San Clemente Islands, as sites of steady and high *S. franciscanus* recruitment due to the influence of the Southern California Eddy. However, these same islands are also areas where survival of mid-sized red sea urchins is poor due to intense predation pressure. Thus, it may be beneficial to establish arrays of collectors on these islands for trans-

Table 2.—Comparison of *Strongylocentrotus intermedius* seed collection in the sea and culture in land-based facilities in Hokkaido. Both methods require intermediate culture with feeding to obtain seed of a suitable size for release in natural habitats (Kawamura, 1987).

Subject	Seed collected in the sea	Seed cultured in land-based facilities
Collecting technique	Planktonic larvae attach to collectors hung in the sea. The system is simple and requires little training.	Larvae are cultured from fertilized eggs. The process is complex and requires specialized training.
Collecting facilities	Collector construction, suspension, and protection from waves are relatively simple.	Complex facilities are required for supplying water, culturing larval food and young sea urchins.
Operations	Minimal labor is required for placing longlines and retrieving the collectors.	Labor intensive on a daily basis.
Obtaining consistent numbers of seed	Great variation.	As techniques are perfected, the supply may stabilize.
Vitality of seed	Natural selection occurs. Gene pool is large.	Natural selection does not occur. Gene pool is small.
Region	Limited to areas of good larval availability.	Possible in any ice-free area.

plantation to other sites. Northwest Harbor, a semi-protected site on San Clemente Island, may be ideal for placement of seed collectors.

Whatever their source, seed survival rates are likely to be very area-specific and will have to be determined empirically in California. Miyamoto et al. (1985) found that predation was minimal on seed larger than 15 mm in Hokkaido. In contrast, seastars in southern California commonly consume sea urchins up to 50 mm (Tegner and Dayton, 1981). Spiny lobsters feed heavily on sea urchins to 60 mm and will consume animals as large as 90 mm in aquaria (Tegner and Levin, 1983). There are apparently no invertebrate-feeding fishes such as wrasses in Hokkaido. Sheephead are major sea urchin predators and the senorita, *Oxyjulis californica*, another common wrasse, has been observed picking juvenile sea urchins out of coralline algae and having small sea urchins in its gut contents (Tegner and Dayton, 1977, 1981). The effects of lobster and sheephead predation are apparent in the population structure of red sea urchins on the southeastern Channel Islands[2].

Thus, the Japanese method of broadcasting seed from the surface is clearly inappropriate for southern California, and protective habitats such as adult spine canopies and rock piles will be critical for seeding to be successful. Given the apparent lack of a reasonable size threshold beyond which there is a significant reduction in predation, it may well be more cost-effective to seed a large number of relatively small seed. Seeding may well be more applicable to northern California where predation pressure appears to be lower. When evaluating the Japanese results, it is also important to consider that they harvest sea urchins as small as 40 mm which may be only 2 years old (Omi, 1987). The minimum legal size in California is 76 mm, about 3 years of age[2]. Thus, red sea urchins in California are exposed to predation for a year longer than sea urchins in Hokkaido before they enter the fishery.

Predation during field growout remains one of the major hurdles to successful culture of mollusks (Jory et al., 1984), and no doubt crustaceans and echinoids as well. Jory et al. (1984) reviewed how predators can decimate unprotected mollusk seed and the many different devices which will provide protection—often at considerable cost. They suggest the importance of planting seed at a size of decreased vulnerability and adequately dispersed to minimize predation. As there may be considerable seasonal variability in predation pressure, studies should determine the optimal time of planting as well.

Physical habitat improvements, such as the addition of rock piles to pavement habitats or even soft sediments, represent considerable initial outlay, but there are no operational costs and the results are long lasting. This approach may be especially important for populations of red sea urchins limited by the survival of mid-sized animals. The enthusiasm for physical habitat improvement shown by the Japanese suggests its effectiveness, but their cost calculations appear to include substantial government subsidies. The major obstacle to this approach in the United States may be opposition by other users of the same environment such as net fishermen[16].

Broodstock and nursery protection require no capital outlay but they do entail a cost; some landings must be sacrificed now for the sake of future harvests. Where it is not possible to accomplish this with a maximum size limit, there is also the risk that the animals left by one fisherman will be harvested by someone else. The results of leaving a minimum density of adults behind are likely to be modest, but they may prevent the loss of some fishing grounds, especially on the southeastern Channel Islands where predation pressure is high[2]. Rotating area closures should also be tested. Despite their high fecundities and recruitment rates, sea urchin fisheries can be over-exploited. Taki (1986) described a case where a fishery for *S. intermedius* exceeded recruitment leading to stock deterioration, and sea urchin fisheries in France (Southward and Southward, 1985) and Barbados (Scheibling and Mladenov, 1987) have collapsed. It seems prudent to adopt a conservative approach now to prevent further deterioration of existing stocks until alternate methods of enhancement are tested and put in place.

In these days of budget deficits and limited government means, the cost of any approach to enhancement must be considered in concert with its biological and economic effectiveness. A sea urchin hatchery is a very expensive proposition, especially since it is not clear that seed survival will be adequate in California ecosystems. The sea urchin industry has levied a tax on landings to fund research and development of enhancement methods, but a several-fold increase in funds would be required to finance a hatchery. A logical first step would be to obtain seed from collectors in the ocean, increase their size in intermediate culture, and then conduct experiments to assess survival rates in benthic habitats. While research may be required to adapt Japanese methods of seed collection to California conditions, seed obtained in this manner will be relatively inexpensive and still useful for determining whether seed survival is adequate to pursue this approach. Tegner and Barry[2] have identified San Clemente and Santa Barbara Islands as optimal sites for seed collectors; mainland locations such as the Point Loma kelp forest are likely to produce lower but still useful numbers of recruits (Tegner and Dayton, 1981). If seed collection proves to be an efficient method for obtaining juveniles, then there are a number of options regarding who funds the collections, distribution or sale of the seed, and who owns fishing rights after growth to harvestable size—in short, will enhancement require changes in the structure of the fishery?

Capital-intensive approaches to enhancement such as a hatchery or physical habitat improvement projects may require the financial backing of the entire industry. This can be practical if based on landing taxes. Labor-intensive projects such as enhancing food-limited populations are likely to be

difficult to organize on an industry-wide basis but may be ideal for a few individuals if seafloor leases can be obtained. Broodstock and nursery protection needs the support of all fishermen, but the incentive to conserve is likely to be greater where there is local control of the water bottom.

Sea urchins have been an important part of the Japanese diet for hundreds of years and are intensively harvested. National landings averaged 25,000 t for 1978–82, and there was remarkably little variation among the years (Takagi, 1986). In a country where there is little or no distinction between fishing and marine farming, the stability of the sea urchin harvest appears to be based on both traditional fisheries management measures such as effort restrictions, size limits, etc. and various enhancement activities facilitated by the structure of the fishing industry. As the California red sea urchin will soon, if it is not already, be fully exploited and the landings will start to fall, the long-term success of the Japanese is something for Californians to consider.

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The Fish Funnel: A Trawl Modification to Reduce Fish Escapement

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ABSTRACT—In the Gulf of Mexico there is a need to assess the potential of underutilized fish resource stocks before a commercial fishery develops. Standard sampling trawls used in the Gulf are ineffective for sampling the resource, so larger, high opening, bottom trawls have been introduced. The larger trawls are more effective, but most of the faster swimming fish species are able to escape these nets, especially during haul back.

To reduce fish escapement, webbing panels, attached inside the trawls ahead of the cod ends, were tested. Initial tests were conducted with two single panel designs—a fish flap and a "floppa." Neither design reduced fish escapement. The floppa distorted the trawl webbing and actually increased fish escapement.

A multi-panel conical funnel design (the fish funnel) was tested and found to increase fish retention by trapping the fish after they passed through it. When used in combination with a technique known as pulsing the trawl, the fish funnel substantially increased trawl catch rates with no indication of fish escapement.

Introduction

Latent or underutilized fish resources in the Gulf of Mexico represent a large biomass of potential commercial importance (Houde, 1976, 1977a, b, c; Reintjes, 1980). The consequence of large-scale fishery development, however, could have a major ecological impact not only on latent resource stocks but also on other species in the food chain. Generally these stocks have received little study. Collection of biological and ecological data is needed before an effective management plan can be developed to protect the resource.

For reliable results, efficient sampling gear has to be used to assess Gulf latent fish resources. Standard sampling trawls used in the Gulf were considered to be too small and inefficient for reliable sampling. Because of their success in similar fisheries in other areas, large-mesh, high opening, bottom trawls were selected to serve as sampling trawls and evaluations were conducted to determine their efficiency.

Early in the evaluation process, a problem was identified when sampling herring and herring-like species collectively known as coastal herrings (Table 1). These fishes are strong swimmers capable of outswimming a trawl at normal speeds of 3.0-3.5 knots. Signs of the problem were evident during net retrieval, when fish were observed gilled in trawl meshes and lying in the belly webbing well ahead of the cod end. Scuba divers noted that coastal herrings encountered during trawl evaluations had no problem keeping up with the trawls, and that, during haul back, they would exit at the slightest hesitation of the net or when the trawl webbing started to go slack.

In an effort to prevent fish escapement, webbing panels were incorporated into the sampling trawls and tested. The first webbing panel tested was a fish flap similar in design to those used by Danish and Norwegian side trawlers. The fish flap was attached inside the trawl ahead of the cod end. The intent was for the webbing panel to flap down at the end of a tow and hold the catch in the cod end. During evaluations, however, divers observed that the fish flap remained flush with the trawl webbing during haul back and did not prevent fish from escaping.

Next, a webbing panel known as a "floppa" (Hodson, 1953) was tested. The floppa is a single-panel, wedge-shaped funnel design that is attached ahead of the trawl cod end with its back opening to the bottom of the trawl. Evaluations showed that the floppa was not only unsuccessful at preventing fish from leaving the cod end; it also distorted trawl meshes at the point of attachment, increasing the possibility of fish escapement.

Last to be tested was a multi-panel conical funnel similar in design to the funnels used in combination with trawl separator devices developed in the United States (Watson, 1982; Taylor, et al., 1985; Watson et al., 1986) and Norway (West et al., 1984). Unlike the separator-device funnels which help to exclude parts of the catch, the

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Table 1.—Gulf of Mexico coastal herrings

Common name	Scientific name
Atlantic thread herring	*Optisthonema oglinum*
Spanish sardine	*Sardinella aurita*
Round herring	*Etrumeus teres*
Scaled sardine	*Harengula jaguana*
Rough scad	*Trachurus lathami*
Round scad	*Decapterus punctatus*
Bigeye scad	*Selar crumenophthalmus*
Atlantic bumper	*Chloroscombrus chrysurus*
Chub mackerel	*Scomber japonicus*

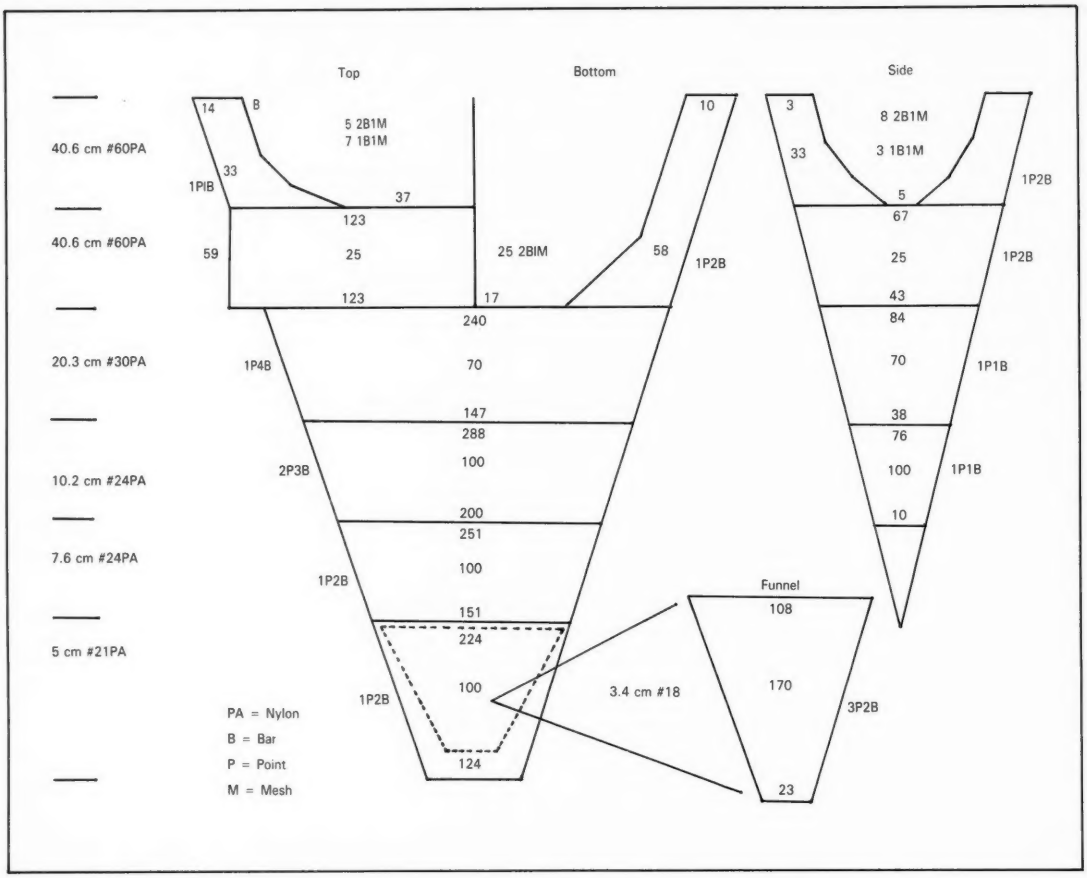

Figure 1.—NMFS trawl with two-panel fish funnel.

conical funnel, herein called the fish funnel, was designed to trap fish in the trawl. The potential of the fish funnel was evident from the first tests, and we continued to modify and perfect the design to develop an effective latent fish resource sampling trawl. This paper describes the methods and results of the tests conducted with the fish funnel.

Materials and Methods

A 40.6 cm mesh NMFS trawl and an 80 cm mesh Shuman trawl[1] were used in testing the fish funnel. The NMFS trawl is a basic four-panel trawl design with the taper beginning at the leading edge of the wing tips (Fig. 1). Mesh sizes reduce from 40.6 cm at the front of the NMFS trawl to 5 cm meshes ahead of the codend.

The Shuman trawl, also a four-panel design, has overlapping jibs (Fig. 2). Mesh sizes in the Shuman trawl reduce from 80 cm leading meshes to 5 cm meshes ahead of the codend.

Two fish funnel designs were tested. A two-panel funnel was tested with the NMFS trawl (Fig. 1). Constructed from 5 cm mesh nylon webbing, the two panels were 100 meshes deep and cut with a four bar-one point taper on each side. The two-panel funnel was attached at the leading edge of the 5 cm joining round on the NMFS trawl.

The Shuman trawl was fitted with a four-panel funnel (Fig. 2). Initial construction material was 3.4 cm nylon webbing. This was later changed to 3.4 cm heat-set and depth-stretched polyethylene webbing. Each panel was 192 meshes deep and cut on a two bar-one point taper on each side for 120 meshes. The remaining 72 meshes were cut on a two bar-three point taper. The four-panel funnel was attached at the leading edge of the 8 cm

[1]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

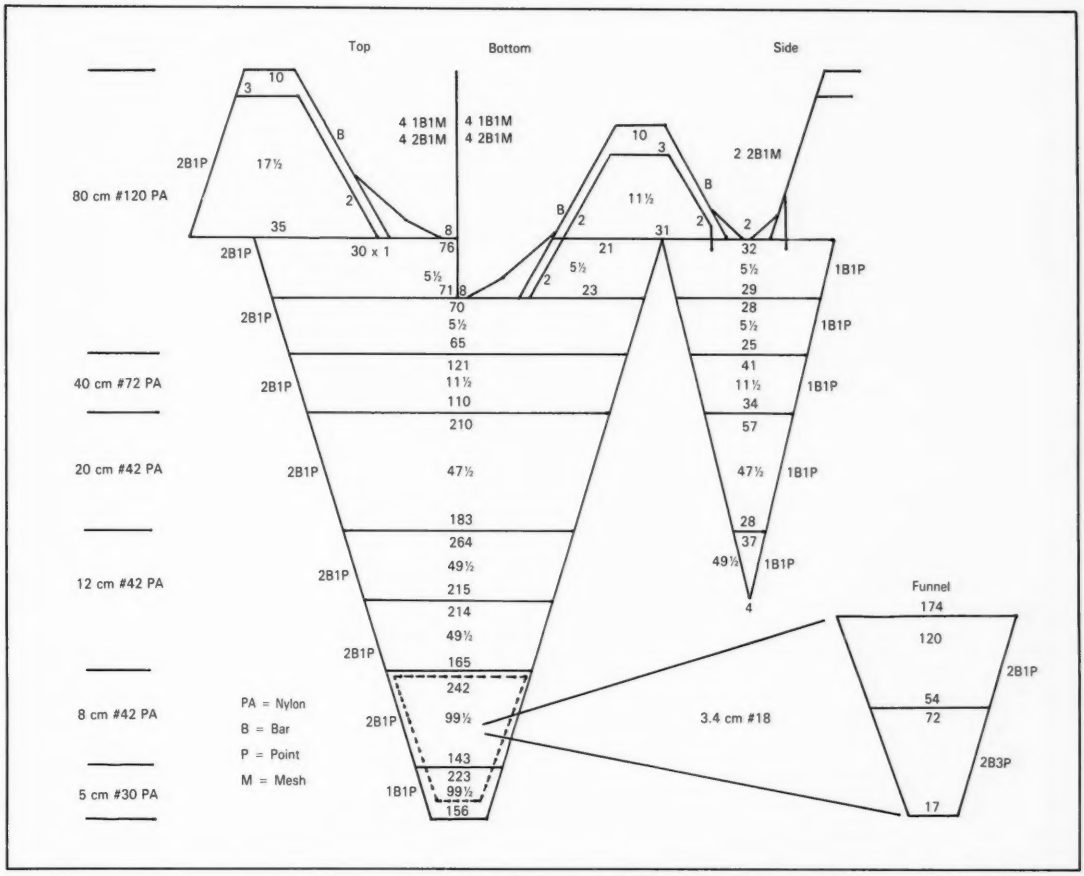

Figure 2.—Shuman trawl with four-panel fish funnel.

joining round on the Shuman trawl.

Evaluations were conducted from the NOAA Ships *Chapman* and *Oregon II* working in the northeastern Gulf of Mexico in depths of 20 to 300 m. Test tows were made at 3-3.5 knots, and on most tows the trawl was pulsed up to 4 or 5 knots for 5 minutes just before hauling back. Methods of evaluations included scuba diver measurements and observations, observations with a remote control underwater video camera system, and fishing tests.

Scuba diver measurements and observations were conducted in 20-30 m of water using standard trawl diving techniques (Wickham and Watson, 1976; Workman et al., 1986; Workman, 1987). Divers first determined the position for the fish funnel by observing the trawls under normal towing conditions. They looked at trawl taper, mesh size and circumference to determine the best point of attachment. Following installation and determination of proper fit and form, divers observed water flow through the fish funnel with the aid of rhodamine B dye injected at the back opening and to the side of the funnel. Water flow speeds in and around the funnel were measured with a General Oceanics current meter rigged for diver operation. Divers used 8mm video cameras, contained in underwater housings, to record fish behavior in relation to the fish funnel. These recordings were studied later in the laboratory.

Manta II, a remote control underwater vehicle equipped with still and video cameras, was used to observe the fish funnel equipped trawls in depths beyond the safe working limits for divers. After the net had been set, Manta II was deployed from the research fishing vessel and "flown" into position by the vehicle pilot using an on board control console. Observations made with Manta II were mainly to determine if any changes occurred

in trawl or funnel configuration when moved from shallow to deeper water.

Fishing tests with the funnel-equipped trawls were conducted in areas where fish were detected using depth sounding instrumentation aboard the research vessel. Fishing times normally ranged from 15 to 30 minutes, and, at the end of the tow, the trawl was pulsed before haul back. As the net was hauled on deck, attention was paid to the location of fish in the net and if any gilling had occurred in either the net or funnel.

Results

Initial evaluations were made by scuba divers on the two-panel fish funnel installed in the NMFS trawl. Although the funnel performed reasonably well, it did not have an optimal shape, and, due to its 5 cm webbing construction, fish gilling in the funnel was a problem. The two-panel funnel was replaced with the four-panel design constructed with 3.4 cm webbing.

Dye flow studies conducted with the four-panel fish funnel showed that water flow was greater at the back opening than to the side of the funnel. Water flow speeds measured in the funnel corresponded closely with the towing speed of the vessel (Table 2). Water flow to the side of the funnel, depending on towing speed, ranged from about 40-50 cm per second slower than flow in the funnel.

Divers observed that, given enough time, most of the fish species of concern would drop back through the funnel at a towing speed of 3.5 knots. After passing through, the fish would either continue to fall back into the cod end or would swim to the side of the funnel where water flow was reduced. Pulsing the trawl at the end of the tow helped to ensure that fish ahead of the funnel were forced through it. Once the fish passed through the funnel, escape—even if the trawl came to a stop during haul back—was nearly impossible unless the funnel failed to perform properly.

The first funnels tested were constructed from nylon webbing. When new, the nylon funnels had good shape and performed well. However, as the nylon aged it stretched and lost its shape. Divers observed that fish gilling and debris clogging in the funnel became more of a problem as the nylon funnels aged. The back openings on the older nylon funnels stretched and would not close properly when the trawl was slowed. The nylon webbing was replaced with heat set and depth stretched polyethylene webbing to prevent the funnel from stretching out of shape. The polyethylene funnel held its shape better and had less gilling problems than the nylon funnel.

Manta II evaluations of a funnel equipped trawl were conducted at a depth of 80 m. The funnel maintained its shape with no differences observed in the funnel or trawl from what had been observed by divers in shallow water.

No fish loss was observed during fishing trials when the trawls were equipped with funnels. When the nets were hauled and brought on board, all of the fish were behind the funnel. Fish gilling was only a problem in the nylon funnels that had stretched with use.

Table 2.—Measurements of water flow ahead, behind, and to the side of the fish funnel at 3.0 and 3.5 knots towing speeds.

Towing speed (kt – cm/sec)	Ahead of funnel (cm/sec)	At back opening of funnel (cm/sec)	To side of funnel (cm/sec)
3.0 – 154	150	156	105
3.5 – 180	171	173	130

Table 3.—Comparative maximum catch rate (metric tons per hour) for select latent fish resources caught with experimental bottom trawls operated from NOAA research vessels (1985–1987).

Species	1985	1986[1]	1987[1]
Gulf butterfish, *Peprilus burti*	12.8	7.2	45.4
Rough scad, *Trachurus lathami*	1.7	3.1	4.6
Driftfish, *Ariomma bondi*	1.0	0.8	3.9
Round herring, *Etrumeus teres*	0.4	1.2	9.1
Chub mackerel, *Scomber japonicus*	0.7	1.5	0.8

[1]Fish funnel used in the latter part of 1986 and all of 1987.

Although no statistical analysis can be applied due to possible temporal and spatial variations in fish abundance, the efficiency of the fish funnel is indicated in a comparison of maximum catch rates for selected target species by year on Table 3. The fish funnel was introduced in the latter part of 1986 and used throughout 1987. Sampling effort remained almost constant over all 3 years while maximum catch rates for most species increased substantially when 1987 is compared to 1985.

Discussion and Conclusions

Prior to the development of the fish funnel, we lacked an effective method for sampling fast swimming fish species in the Gulf of Mexico. Standard sampling trawls were relatively small and inefficient for sampling these faster swimmers. The introduction of large-mesh trawls and faster towing speeds improved catch rates but did not prevent fish escapement. Catches were larger because the larger nets caught more fish, but the escapement problem remained unsolved until the development of the fish funnel.

A properly performing fish funnel virtually eliminates fish escapement. Fish funnel performance, as determined by diver observations and fishing tests, depends on: 1) Funnel shape, 2) position in the trawl, 3) mesh size, and 4) construction material.

A slow taper gives the funnel a smooth shape and ensures that no humps or pockets form. Humps and pockets cause catch and debris to collect and increase the probability of fish gilling.

Funnel placement is determined by trawl mesh size and circumference. Fish will escape if the funnel is attached at a point where the surrounding trawl meshes are too large. However, if it is attached where trawl circumference is too small, the taper and opening of the funnel may be too small to allow larger fish and objects in the catch to pass.

Fish gilling is a problem if the funnel is constructed from meshes 5 cm or larger or from the wrong webbing

material. To prevent the funnel from stretching or becoming distorted, heat-set and depth-stretched polyethylene webbing is used in construction. To ensure that the funnel closes properly if trawl speed slows, small floats are attached to the underside near the back opening of the funnel.

Pulsing the trawl at the end of the tow further increases the efficiency of the funnel equipped trawl. By speeding up to about 5 knots before hauling the net back, fish ahead of the funnel are forced through.

The NMFS Mississippi Laboratories, using fish funnel equipped trawls in combination with pulsing the trawl, are now able to sample coastal herrings and other fast swimming species effectively. We now have the capability to collect biological and ecological data on latent fish resources in the Gulf of Mexico.

Acknowledgments

Special thanks go to John Watson, John Mitchell, and Jim Barrett. Without their help and effort, there probably would not be a fish funnel. Thanks are also due to the officers and crew of the NOAA Ships *Chapman* and *Oregon II* for support provided in evaluating and testing the fish funnel and to Chris Gledhill, Ren Lohoefener, and Warren Stuntz for suggestions and constructive criticism on the manuscript.

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Size-related Hooking Mortality of Incidentally Caught Chinook Salmon, *Oncorhynchus tshawytscha*

ALEX WERTHEIMER, ADRIAN CELEWYCZ, HERBERT JAENICKE, DONALD MORTENSEN, and JOE ORSI

ABSTRACT—Mortality associated with the incidental catch and release by commercial trollers of two size classes of chinook salmon, Oncorhynchus tshawytscha, *was assessed. Observed cumulative mortality 4–6 days after hooking was 18.3 percent for sublegal-size fish (< 66 cm FL) and 19.0 percent for legal-size fish. Size of fish was not significantly related to mortality; however, when the results were combined with data from a previous experiment, there was a significant inverse relationship between fish length and mortality. Hooking mortality estimates calculated from tagging experiments and observed relative mortality of legal- and sublegal-size fish held in net pens, were used to derive a range for total hooking mortality of 22.0–26.4 percent for sublegal-size chinook salmon and 18.5–26.4 percent for legal-size chinook salmon.*

Introduction

To rebuild depressed and declining chinook salmon, *Oncorhynchus tshawytscha*, stocks of the northeastern Pacific rim, the Pacific Salmon Commission has established limits on the numbers of chinook salmon that can be landed in several commercial fisheries. One result has been a dramatic reduction in fishing seasons for chinook salmon in some areas. In Alaska, the summer season (April–September) for commercial trolling has been reduced from 179 days in 1980 to 12 days in 1988. A consequence has been an increase in chinook-only closures, during which fishing is directed primarily at coho salmon, *O. kisutch*, and all chinook salmon caught must be released. Fisheries managers require estimates of the mortality associated with such catch and release periods to assess their effect.

Previous estimates of hooking mortality for chinook salmon vary widely, from 12 percent (Butler and Loeffel, 1972) to 71 percent (Parker and Black, 1959). Reviewers of hooking mortality research have proposed estimates of ≤30 percent (Wright, 1970), 38 percent (Horton and Wilson-Jacobs, 1985) and 50 percent (Ricker, 1976). Most estimates focus on sublegal-size fish or do not consider size-related differences in mortality. Wertheimer (1988) concluded that hook and release mortality of sublegal-size chinook salmon is around 25 percent (agreeing with Wright's conclusion that "estimates of mortality higher than 30 percent are excessive"). Wertheimer (1988) also observed a lower mortality rate (20.5 percent) for legal-size chinook salmon; however, the sample size for this estimate was small and the 95 percent confidence interval was large (9–32 percent). To increase the sample size of legal-size fish, we carried out additional research on hooking mortality of chinook salmon to determine if the mortality rates are different between sublegal- and legal-size classes.

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Methods

Gear

Three power trollers were chartered to fish 4–12 August 1987 at Whale Bay on the outer coast of Baranof Island in southeastern Alaska (Fig. 1). Each vessel fished four wire lines with 8–10 individual lures per line. To simulate fishing during chinook-only closures, the fishermen used their normal complement of coho salmon lures, including plugs, spoons, and hootchies (imitation squid) with flashers. Hook size was limited to 6/0 barbed, single hooks, the most common size used during chinook-only closures. The numbers of each lure type fished were recorded for each vessel throughout the fishing period.

Processing the Catch

When a chinook salmon was caught, it was led by the fisherman to an electric basket (Orsi and Short, 1987) where it was simultaneously lifted from the water and immobilized by electric shock. The hook was removed by the fisherman who inserted a gaff hook along the curve of the lure hook and turned the gaff so the weight of the fish pulled it free of the hook. An observer noted lure type, depth fished, and location of the wound, and then rated the severity of the wound according to the following condition codes, after Davis et al., 1986: Condition 1, a minor injury, including hooking near the outer portion of the mouth and little or no bleeding; condition 2, a serious injury, including hooking in or near the gills or eyes, and severe bleeding; or condition 3, dead. Fork lengths (FL) of fish were measured to the nearest centimeter. On the basis of conversions given by Van Hyning (1951), FL of 66 cm was considered equivalent to the legal size limit of 70

cm total length. Fish were marked with a 2.7-cm numbered Floy[1] anchor tag inserted below the dorsal fin. Average processing time was less than 45 seconds. The observer also noted if a fish suffered severe handling stress such as abnormally long processing time, extensive descaling (>15 percent), or being dropped during transfer.

A high catch rate of chinook salmon made it necessary to limit the number of fish retained to avoid exceeding the holding capacity of the net pens. All legal-size fish were retained, and after the second day of fishing each boat was limited to retaining the first 15 sublegal-size fish caught each day. All coho salmon caught were killed, dressed, iced, and sold to help defray the cost of the project.

Each retained chinook salmon was placed in a covered 175-liter live tank with flowing seawater until it was transferred with a large dip net (84 × 51 cm, 6 mm knotless webbing) to a similar tank in a skiff. Typically, only one or two fish were held at a time in each live tank. Live fish were transferred from the skiff to a net pen by pouring the contents of the live tank into the pen. Transfer time from capture to the net pen varied from 6 to 40 minutes and averaged 18 minutes.

Two net-pens, constructed of 2.5 cm knotless nylon mesh suspended from a 12.2 m^2 float frame, were used. Each pen had eight sides that were 12 m deep and were alternately 9.1 and 2.2 m long. The bottom sagged to a depth of 15 m; total volume was 1,700 m^3. Fish from the first 3 fishing days were placed in net pen 1 and fish from the next 3 fishing days were placed in net pen 2. At the end of the sixth fishing day, pen 1 was emptied by releasing the fish, then fish from the final 3 fishing days were placed into it. The fish in pen 2 were released at the end of the ninth fishing day, and the second group of fish in pen 1 were released 3 days later. Thus, all fish held were observed 4–6 days. The pens were checked by divers at the end of each fishing day and for 3 days after trolling ended; dead fish were removed and the tag number was recorded. Most (155 of 168) dead fish were examined postmortem and the location of the primary wound site was noted. Temperature and salinity profiles near the holding nets and on the fishing grounds were measured by bathymetric casts with a recording conductivity-temperature instrument.

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

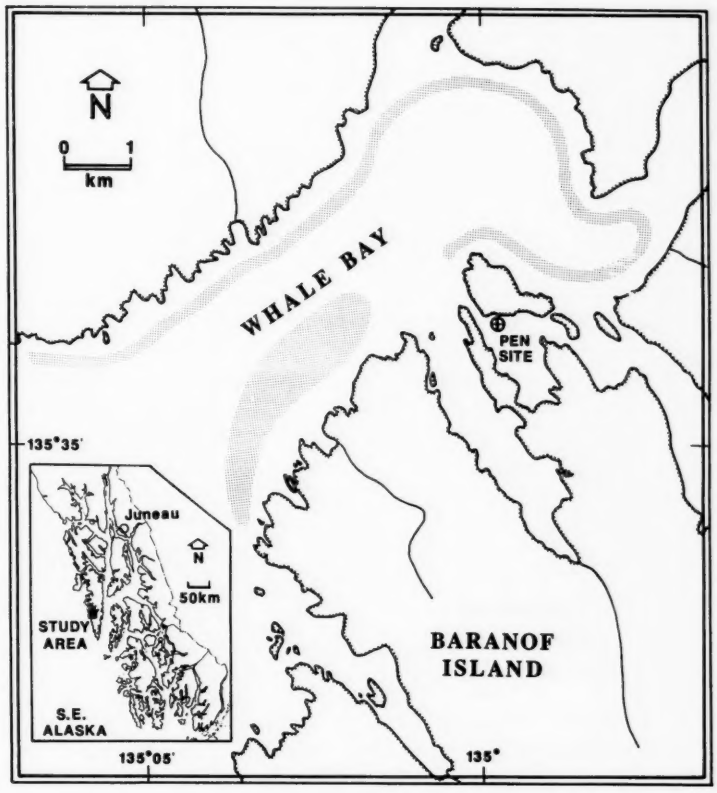

Figure 1.—Fishing areas (stippled) and net-pen site used for study in Whale Bay, August 1987.

Statistical Analysis

The BMDPLR stepwise logistic regression program (Dixon et al., 1983) was used to identify the independent variables significantly related with mortality (the binary response variable). For the logistic regression model the probability of mortality is:

$$e^u / (1 + e^u)$$

where u is a linear function of the independent variables. The variables considered in the regression model were injury location, fork length, vessel, lure depth, lure type, and transfer time. An independent variable could be included in the regression model if the improvement chi-square test, computed from the log e of the ratio of the likelihood function without the variable to the likelihood function with the variable, was significant ($P < 0.05$). Two stepwise regression analyses were performed based on when mortality occurred. In the first analysis, all

mortalities were included, and in the second, fish that were dead prior to transfer to the net pens were excluded from the model.

The relationship between fish length and mortality was examined using logistic regression and by generating smoothed curves of the mortality rates plotted against length, using the 4253H smoothing algorithm (Velleman and Hoaglin, 1981). It was necessary to pool the observations for smoothing into 3 cm increments to have sufficient (> 10) observations at each length increment. Data from this study and Wertheimer (1988) were examined.

Mortality was determined for each of seven time periods: Immediate (fish dead at landing or by the time of transfer to the net pens) and at the end of each of the 6 days that each group of fish were held. The BMDP3R nonlinear regression program (Dixon et al., 1983) was used to generate maximum likelihood estimates with associated standard deviations for each time period, and the correlation matrix for the estimates. Total mortality during the study is the sum of the estimates for each time period; the variance of this estimate is the sum of the variances for each time period plus the sum of the variance-covariance matrix (Mood and Greybill, 1963).

Estimates of delayed mortality of sublegal-size chinook salmon observed in this study were compared with estimates of delayed mortality recalculated from previous tagging experiments (Butler and Loeffel, 1972; Wright, 1970). The tag-recovery data was recalculated by replacing their assumption of no delayed mortality for the group with the highest tag recovery rate with a mortality rate observed in the present study. A recapture coefficient was calculated from the formula

$$r = n/(N' - D), \qquad (1)$$

where n is the number of recaptures for the group with the highest tag recovery rate, N' is the number of tags released from this group, and D is the number of delayed deaths for this group. The number of deaths due to delayed mortality in a particular category can then be determined by the formula

$$D_i = N_i' - n_i/r, \qquad (2)$$

where i is a particular wound location or condition. Delayed mortality expressed as the proportion of fish landed would be the sum of the D_i's divided by N, where $N = N' + I$ and I is the number of immediate deaths.

Table 1.—Summary of stepwise logistic regression results for chinook salmon caught at Whale Bay in 1987. Analysis 1 included all observations of mortality in the model, and analysis 2 excluded observations of immediate mortality from the regression model and included transfer time as an independent variable. Improvement chi-square is shown only for variables that enter the stepwise model. Asterisks denote significant differences at $P < 0.05$* or $P < 0.001$*.**

Analysis and variable	Approximate F, no other variables in model	Step to enter model	Improvement χ^2
Analysis 1			
Injury location	24.10***	1	147.64***
Depth	5.70*		
Lure type	3.28*		
Vessel	2.01		
Length	0.04		
Analysis 2			
Injury location	17.83***	1	108.63***
Depth	5.70*		
Lure	1.97		
Length	1.50		
Transfer time	0.71		
Vessel	0.69		

Results

A total of 550 legal- and 701 sublegal-size chinook salmon were caught and landed. All legal-size fish and 363 sublegal-size fish were included in the mortality analysis; 338 sublegal-size fish were tagged and released immediately following capture. All fish but one were caught at depths greater than 12 m; 99 percent of the legal-size fish and 98 percent of the sublegal-size fish were caught at depths greater than 15 m, the maximum depth in the pen. Most (83 percent) fish were caught in depths below 30 m; the maximum depth at which fish were caught was 58 m. Once in the holding pens, fish in good condition remained in the lower half of the net pen.

Water temperature was 1–2°C warmer in the lower half of the net pen compared with temperatures in Whale Bay at the depths most of the fish were caught. Temperatures in the net pens were 10.7–11.3°C at 5 m and 8.6–9.0°C at 15 m. Temperatures in the fishing area were 9.0–9.2°C at 30 m and 7.9–8.0°C at 60 m. Salinity was also slightly lower in the net pens. Salinity in the pens was 30.5–31.0‰ at 5 m and 30.5–31.3‰ at 15 m. Salinity in the fishing area was 31.5–31.6‰ at 15 m and 31.7–31.9‰ at 60 m.

Variables Affecting Mortality

In the stepwise logistic regression, only injury location entered and remained in the model in both analyses (Table 1). In the analysis that included both immediate and delayed mortality, the location, depth of capture, and lure type were significantly associated with mortality when the variables were considered in isolation, i.e., when each variable was entered in the logistic regression model independently (Table 1). In the analysis that excluded immediate mortality (to include transfer time as a variable), injury location and depth of capture were significantly associated with mortality when the variables were considered in isolation (Table 1). These results indicate that there is some correlation of injury location with lure type and depth fished.

The relationship between the location of the hooking injury and mortality is apparent from the observed mortality rates for both legal- and sublegal-size fish. Mortality for both size classes was 85 percent for fish hooked in the gills, and ranged from 0 to 10.9 percent for fish hooked in the snout, maxillary, and corner of the mouth (Table 2). When observations for the two size classes are combined, the injury locations can be grouped into three general categories according to degree of mortality (Fig. 2): Low—snout, maxillary, or corner of the mouth; intermediate—lower jaw, isthmus, cheek, or eye; and high—gills. In general, these groups correspond to the proximity of the wounds to the gills and the complex of blood vessels in the isthmus at the base of the gills. Postmortem examinations verified that the wound location influences mortality. Gill damage and eye or isthmus wounds were apparent in 95

percent of the fish examined after dying. Gill damage was observed in 76 percent of the fish examined postmortem, although only 21 percent of the fish that died were observed to have gill injuries at landing.

As indicated by the logistic regression analysis, the relationship between lure type and mortality was due to a correlation between lure type and injury location. Fish caught on plugs had lower mortality and were hooked more frequently in "low" mortality locations than fish caught on the other lure types (Table 3). There was considerable selection by the fish for plugs; although plugs comprised only 12 percent of the lures fished, they caught 34 percent of the fish (Table 3). In contrast, spoons comprised 58 percent of the lures fished but caught only 14 percent of the fish.

The relationship between injury location and depth of capture indicated by the logistic regression is not clear. One explanation is that different lure types were fished at particular depths, and because lure type and injury location are related, there is a relationship between depth and injury location. This explanation cannot be confirmed, however, because the relative proportions of lure types fished at particular depths were not recorded.

There was no evidence of direct increases to mortality due to transfer time or handling stress. If fish that were alive at landing, but died before transfer into the net-pen are included in the regression analysis that considers transfer time, there is actually a significant inverse relationship between time in the tanks and mortality. However, this does not mean that increasing transfer time will reduce mortality; higher mortality associated with shorter tank time is caused by mortality wounded fish that still show some respiratory response at landing, but die shortly after being placed in the holding tanks. For this reason, all fish that died prior to placement into the net-pens were considered immediate mortality.

Mortality was lower for fish that were exposed to excessive handling stress relative to fish that were not exposed to such stress. Of 73 fish that were noted to have suffered severe handling stress, such as being dropped during transfer or descaled extensively, 15.1 percent died, compared with 18.7 percent mortality for fish exposed to normal handling. It is unlikely that increased stress reduces mortality; however, these data suggest that increases in handling stress did not result in greater mortality.

Condition at Landing

Of the 913 chinook salmon in the experiment, 53.8 percent (491 fish) were graded condition 1 (minor injury), 45.8 percent (418 fish) were

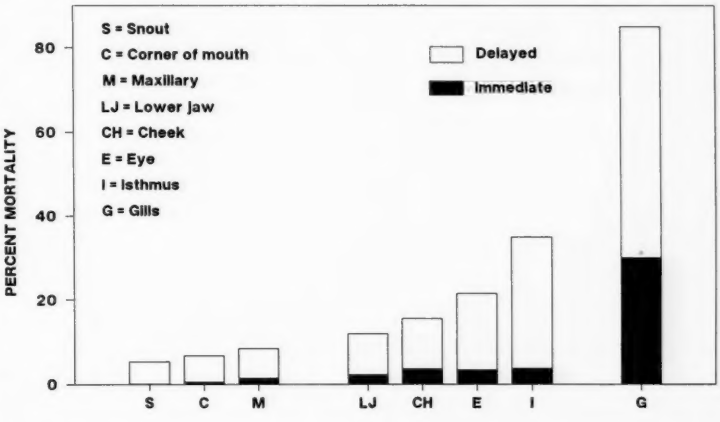

Figure 2.—Immediate and delayed mortality according to location of hooking injury for chinook salmon caught in Whale Bay in August 1987; all sizes combined.

Table 2.—Total catch and subsequent mortality by hooking location and size class of chinook salmon captured at Whale Bay in 1987. Immediate mortality includes all fish that died prior to transfer into the holding nets; delayed mortality is the total number of deaths minus the immediate deaths, divided by the total number captured; it is not weighted for length of time the fish were held.

Hooking location	Legal-size fish				Sublegal-size fish			
	Total catch	Mortality (%)			Total catch	Mortality (%)		
		Immediate	Delayed	Total		Immediate	Delayed	Total
Snout	31	0	9.7	9.7	26	0	0	0
Corner of mouth	117	0.9	6.8	7.7	93	0	5.4	5.4
Maxillary	46	0	10.9	10.9	25	4.0	0	4.0
Cheek	51	3.9	11.8	15.7	33	3.3	12.1	15.4
Lower jaw	85	1.2	7.1	8.3	51	3.9	13.7	17.6
Eye	132	2.3	18.9	21.2	73	5.5	16.4	21.9
Isthmus	68	4.4	33.8	38.2	41	2.4	26.8	29.2
Gills	20	20.0	65.0	85.0	20	40.0	45.0	85.0
Other					1	0	0	0

Table 3.—Effort, catch, catch by wound category, and percent dying for three lure types. Effort is the percent of the total gear-hours each lure type was fished. Catch is the percent of the total landings caught by each lure type. Wound category is the percent of the landings that occurred in a particular wound category; see text for wound locations included in each wound category.

Item	Lure type		
	Hootchie	Spoon	Plug
Effort	30	58	12
Catch	52	14	34
Wound category			
High mortality	5	8	2
Intermediate	62	60	53
Low mortality	33	32	45
Percent dying	20	22	14

graded condition 2 (severe injury), and 0.4 percent (4 fish) were assessed as dead at landing. Mortality of condition 1 fish subsequent to landing was 8.4 percent, significantly lower (χ^2 = 67.823, df = 1, $P < 0.001$) than the 29.5 percent mortality of condition 2 fish.

Total Hooking Mortality

When the maximum likelihood estimates of immediate and daily mortality rates were summed, the estimated total mortality was 18.3 percent for sublegal-size and 19.0 percent for legal-size fish (Table 4). The pattern of mortality over the 6-day holding period was similar for both size classes: High mortality the day of capture, declining to no mortality on day 6 (Table 4). The 95 percent confidence intervals for total mortality were 14.0–22.6 percent for sublegal-size fish and 15.5–22.5 percent for legal-size fish.

To recalculate the mortality estimates of Butler and Loeffel (1972) for chinook salmon of sublegal size, an estimate of delayed mortality was substituted for their assumption of no delayed mortality for maxillary-hooked fish. Only 25 sublegal-size fish were hooked in the maxillary in our study (Table 2), with no delayed mortality observed; therefore, fish with hooking injuries that resulted in low delayed mortality (maxillary, snout, or corner of the mouth) were pooled to derive a delayed mortality rate to substitute for the assumption of no delayed mortality in maxillary-hooked fish. There were five delayed deaths out of 144 sublegal-size fish in this group (Table 2), or 3.5 percent; weighted for the number of days held, the mortality rate is 4.2 percent. Wertheimer (1988) used the same wound locations, with the addition of cheek-hooked fish, in his assignment of hooking locations with low mortality. Mortality for cheek-hooked sublegal-size fish was in the intermediate range in our study, with a delayed mortality of 12.1 percent. If cheek-hooked fish are included in the pool of injury locations causing low mortality, delayed mortality was 5.1 percent (9 of 177) fish; weighted for the number of days held, the rate is 5.6 percent.

Equations (1) and (2) were used to estimate the numbers of delayed deaths for all injury locations reported in Table 5 of Butler and Loeffel (1972). If the 4.2 percent mortality rate observed for the low mortality category was substituted for the assumption of no delayed mortality, the recalculated delayed mortality was 17.2 percent. Total mortality, including the 8 percent immediate mortality reported for barbed hooks by Butler and Loeffel (1972) for this tag recovery data set, would then be 25.2 percent. If the 5.6 percent mortality rate observed when cheek-hooked fish are included in the low mortality category was used, the recalculated delayed mortality was 18.4 percent, and total mortality would be 26.4 percent.

Recalculation of data on tag recovery by condition for chinook salmon (Wright, 1970) was done similarly. The delayed mortality of 8.4 percent observed in our study for condition 1 fish was used to replace the assumption of zero mortality for "good" fish reported by Wright (1970). This mortality rate was for all sizes combined, because Wright's (1970) data included both legal- and sublegal-size fish. The recalculated estimate with this value was a total delayed mortality of 15.5 percent based on number of fish tagged. If an immediate mortality of 8 percent was assumed, delayed mortality was 14.2 percent based on number of fish landed, and total mortality was 22.2 percent.

Fish Size and Mortality

Mortality was not significantly associated with fish size in the 1987 data, however, Wertheimer (1988) did find a significant relationship in a 1986 study. When the data from both years were combined, there was a significant ($P < 0.01$) relationship identified by logistic regression between size and mortality (Table 5). If the combined data set was split into legal- and sublegal-size fish, there was a significant ($P < 0.01$) effect identified over the sublegal size range (27–65 cm), but not over the legal size range (66–106 cm). This indicated that the effects of fish size on mortality occurred in the sublegal size range.

Smoothed curves of mortality rate as a function of fish size pooled for 3 cm increments also indicated differences in mortality with size (Fig. 3). The data for both years pooled indicated a higher mortality rate for smaller fish, and then a rapid decline between 50 and 53 cm. Mortality rates continued to decline for the combined data until 62 cm, and then gradually increased with fish size.

The graphed representation of mortality rate as a function of fish size suggested that the significant inverse relationship between mortality and size identified by logistic regression for sublegal-size fish was due to two

Table 4.—Total numbers of chinook salmon caught and held for various time periods, numbers dying, and the maximum likelihood estimates of mortality. The standard deviation of the summed mortality is the sum of the variances for each time period, corrected for the covariance.

Size of fish and time period	Days in sample	No. of fish		Maximum Likelihood est.	
		Caught	Died	% mortality	SD
Legal-size fish					
Immediate	9	550	14	2.55	0.67
Day 1	9	550	69	12.55	1.41
Day 2	9	550	5	0.91	0.40
Day 3	9	550	5	0.91	0.40
Day 4	9	550	7	1.27	0.48
Day 5	6	371	3	0.81	0.47
Day 6	3	185	0	0.00	0.00
Total mortality				19.00	1.79
Sublegal-size fish					
Immediate	9	363	17	4.67	1.11
Day 1	9	363	41	11.26	1.66
Day 2	9	363	2	0.55	0.39
Day 3	9	363	1	0.27	0.27
Day 4	9	363	1	0.27	0.27
Day 5	6	249	3	1.24	0.72
Day 6	3	124	0	0.00	0.00
Total mortality				18.26	2.18

Table 5.—Logistic regression of mortality on fish size for chinook salmon hooked on commercial troll gear in 1987 (current study) and 1986 (Wertheimer 1988), for both data sets combined. Asterisks denote significant F values at $P < 0.01$ or $P < 0.001$***.**

Fish size (range, cm)	Approximate F to enter model	Regression coefficient
All (27–106)	7.15**	−.017
Legal (66–106)	0.72	
Sublegal (27–65)	12.42***	−.039

levels of mortality: High for fish < 53 cm, and low for fish > 53 cm. If the data were split around this 53 cm inflection point, maximum likelihood estimates of mortality for both 1986 and 1987 data showed that fish < 53 cm had the highest mortality rate, relative to both larger sublegal-size fish and legal-size fish (Table 6). When the data for both years were combined, the maximum likelihood estimate of morality for fish < 53 cm was 28.3 percent, 1.62 times the 17.5 percent rate estimated for larger sublegal-size fish (Table 6). The mortality estimate for legal-size fish in 1986 and 1987 combined was 18.5 percent, 1.06 times the rate of the larger sublegal size category. Note that the estimates from the combined data were in some cases slightly outside the range of the estimates for each year; this was due to the effects of sample size in the estimation of daily mortality increments, especially where small samples had been heavily weighted in the uncombined data. In the combined data sets, estimated mortality of legal-size fish was 85 percent of the estimated sublegal-size rate.

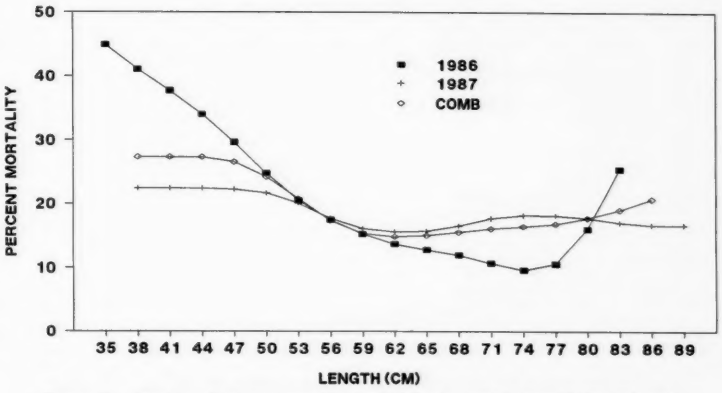

Figure 3.—Hook and release mortality as a function of fork length for chinook salmon caught on commercial troll gear in 1986, 1987, and both years combined. Data were smoothed twice with the 4253H algorithm (Velleman and Hoaglin, 1981). End points of the curves incorporate observations outside the range shown.

Table 6.—Mean size and observed mortality (weighted for time held) of legal- and sublegal-size chinook salmon caught in 1986 and 1987. Sublegal-size fish were partitioned into two groups based on the inflection point of 53 cm observed in Figure 3. Numbers in parentheses are the 95 percent confidence intervals for mortality estimates. Data for 1986 are from Wertheimer (1988).

	Legal (>65 cm)		Sublegal (<66 cm)		Sublegal (<53 cm)		Sublegal (53–65 cm)	
Year	Mean (cm)	Mortality (%)	Mean (cm)	Mortality (%)	N	Mortality (%)	N	Mortality (%)
1986	73.5	20.5 (9.0-31.9)	52.0	24.5 (20.1-29.0)	200	32.4	198	16.8
1987	72.9	19.0 (15.5-22.5)	56.0	18.3 (14.0-22.6)	93	20.4	270	17.4
Combined		18.5 (15.4-21.6)		21.7 (18.6-24.8)	293	28.3	468	17.5

Discussion

Observed mortality rates in this study were lower for both legal- and sublegal-size chinook salmon than those reported in a similar study by Wertheimer (1988). The 95 percent confidence intervals overlapped in both studies for both size classes, indicating the differences may be due to chance. Two other factors that may have contributed to lower mortality rates were size distribution of the catch and lure type.

Size distribution of the sublegal-size fish changed considerably between 1986 and 1987. In 1986, 50 percent of the sublegal-size fish were < 53 cm FL, and in 1987, only 26 percent of the sublegal-size catch was < 53 cm FL (Table 6). However, mortality within this size category was considerably lower in 1987 than 1986, so size distribution alone cannot explain the differences observed between years.

A substantial shift was also observed between 1986 and 1987 in the proportion of fish caught by the three lure types fished. Because there were differences in mortality associated with lure type, this shift may have contributed to the lower mortality rate. The mortality rates of the different lure types were not consistent between years. Although the highest proportion of fish that died in both years had been caught with spoons, this proportion decreased from 31 percent in 1986 (Wertheimer, 1988) to 22 percent in 1987 (Table 3).

The proportion of fish that died changed between years for those caught with hootchies and plugs, increasing from 13 percent in 1986 to 20 percent in 1987 for hootchies, and decreasing from 26 percent in 1986 to 13 percent in 1987 for plugs. The fish may attack the lure types disproportionately and with different levels of aggression depending on the lure depth, water clarity, and prey species composition and density. This variability in the mortality caused by a specific lure type probably contributed to the differences in total mortality observed between years. One conclusion from this interannual variability in mortality by lure type is that none of the three lure types could be conclusively identified as minimizing mortality.

Do the observed mortality rates adequately represent the rates that actually occur in a commercial troll fishery, or are the results biased by the experimental techniques? Wertheimer (1988) examined potential sources of bias in a similar enclosure study, and argued that the close agreement of the observed rates and mortality estimates recalculated from previous tagging studies validated the experimental estimates. In our study, the observed rates over the 6-day holding period were considerably lower than the recalculated rates. The two most important potential sources of bias identified by Wertheimer (1988) were: 1) The stress of handling and holding the fish increased mortality and resulted in an overestimate of the true rate, and 2) mortality due to hooking injuries continued after the duration of the holding period and resulted in an underestimate of the true rate.

The stress of electric shock, tagging, transfer to live tanks, and holding in net pens could have increased mortality. Fry and Hughes (1951) found that holding troll-caught chinook salmon in small live tanks decreased tag recovery rates and Wertheimer (1988) found that longer holding time was associated with increased mortality. Ellis (1964) concluded that holding fish for extended periods in live tanks contributed to the high mortality rates reported for troll-caught chinook salmon by Parker and Black (1959). In our study, there was no indication that length of holding time was related to mortality. Wertheimer (1988) reviewed evidence that the other handling factors listed above do not directly cause mortality; however, these factors could contribute to higher mortality for fish that are already severely stressed by the hooking injury. In our study, fish that were noted to have suffered severe or extraordinary handling stress did not have higher mortality than the rest of the fish sampled. Because increased stress did not result in increased mortality, we concluded that the hooking injury itself, as indicated by the close association of wound location and mortality, was the primary cause of the mortality we observed.

Another possible bias to the observed mortality rates was that mortality was not complete at the end of the holding period. Most mortality occurred by the end of the day the fish were hooked. However, there were fish alive at the end of the 4–6 day holding period that were observed swimming sluggishly with severe injury, typically with an eye torn out or destroyed by hooking. Forty percent of the fish caught in this study that were hooked in the eye or through the orbit of the eye had the eye punctured or torn out. Not all the fish wounded in this way die prior to being caught in a fishery.

We observed three chinook salmon caught during the course of this study with only one functioning eye; we assumed the other eye had been destroyed by a previous hooking incident as the socket was filled with scar tissue. Even though some of these severely injured fish do survive, the probability of their survival has certainly been reduced relative to uninjured fish; therefore we must assume that hooking mortality for fish in this wound category was not complete at the end of the study period.

The recalculation of the tag recovery data of Butler and Loeffel (1972) and Wright (1970) offered a method of estimating total mortality without some of the biases inherent in the original estimates derived from the tag recovery data or identified in our estimates. The recalculated values were based on observed mortality rates for certain categories of fish observed in our study, which replaced the assumption of no delayed mortality for these groups in the original estimates. The estimates based on tag recovery data have no bias due to the incomplete delayed mortality of some severely wounded fish, because the estimate is based on fish surviving until recapture or escapement. The immediate mortality rate used in the recalculated estimate was conservatively high; the 8.0 percent rate used is at the high end of the range of values reported for fish dead at landing (Wright, 1970; Horton and Wilson-Jacobs, 1985), and considerably higher than our observations.

The recalculated estimates of mortality agreed closely for our study and Wertheimer (1988). Our estimates were 25–26.4 percent and 22.2 percent, based on injury location and condition, respectively. Estimates by Wertheimer (1988) were 25.7 percent based on injury location and 23.5 percent based on condition. We think that the use of injury location to determine relative mortality rates is well founded, because of the consistent significance in association between mortality and anatomical hooking site found for a variety of fish species, including chinook salmon in our study and in Butler and Loeffel (1972); coho salmon in Butler and Loeffel (1972); Atlantic salmon, *Salmo salar*, in Warner (1979); lake trout, *Salvelinus namaycush*, in Loftus et al. (1988); and largemouth bass, *Micropterus salmoides*, in Pelzman (1978). The assessment of condition at landing may be more subjective and prone to variability between observers (Wertheimer, 1988) than assessment of injury location.

To place a range on the estimates based on wound location, we examined how the assumptions regarding observed delayed mortality affected the point estimates of total mortality. The estimates of total hooking mortality of sublegal-size chinook salmon based on the injury location varied from 25.7 percent in 1986 (Wertheimer, 1988) to 25.2–26.4 percent in 1987. The variation in these point estimates depended on which injury locations were used to represent delayed mortality of maxillary-hooked fish, the group with the highest tag recovery rate (Butler and Loeffel, 1972). The observed mortality rates used were conservatively high in that the stress of handling and holding the fish may have increased the observed values to some unquantified degree. If all delayed mortality observed for these groups was due to stress, and no delayed mortality for maxillary-hooked fish was assumed, the correctly calculated estimate of total mortality is 22.1 percent (Wertheimer, 1988), the minimum rate that can be calculated from the tag recovery data. Conversely, the 26.4 percent estimate can be considered a maximum rate. It incorpor-

ates any bias due to handling and holding stress, and uses the observed delayed mortality of several injury locations as a conservatively high estimate of the delayed mortality of maxillary-hooked fish. We conclude that the total hooking mortality of sublegal-size chinook salmon is in the range of 22.1–26.4 percent, and that a point estimate of about 26 percent is a realistic and conservatively high estimate of the actual rate.

Based on the lower incidence of dead and seriously injured legal-size chinook salmon relative to that for sublegal-size fish, several authors have concluded that larger chinook salmon suffer lower mortality when hooked and released from commercial troll gear (Parker and Kirkness, 1956; Loeffel, 1961; Davis et al., 1986). In a study using the same methodology as in our study, Wertheimer (1988) observed lower hooking mortality for legal-size chinook salmon and found a significant inverse relationship between fish size and mortality. In contrast, Fry and Hughes (1951) found no difference in tag recovery rates relative to size of chinook salmon tagged, and there was no relationship between size and mortality in our study. When we combined our results with those of Wertheimer (1988), however, there was a significant inverse relationship between size and mortality. This relationship was primarily due to higher mortality of small sublegal-size fish (< 53 cm); there was no significant relationship between size and mortality for chinook salmon larger than the legal size limit. Although there was not uniform consistency among the studies cited, these combined data do indicate that sublegal-size chinook salmon suffer higher hooking mortality than legal-size fish.

We assigned a range of values for the total mortality of legal-size chinook salmon by examining our results in perspective to the biases affecting them. Based on the conclusion that sublegal-size fish have a higher mortality rate, mortality of legal-size chinook salmon should not exceed 26.4 percent, the upper end of the range assigned to the sublegal-size fish. A minimum estimate was the 18.5 percent total hooking mortality we calculated by combining the 1986 and 1987 data for legal-size fish held in net pens (Table 6). This minimum estimate does not account for additional delayed mortality occurring after the holding period, the principal source of bias we identified in such estimates. The mortality for legal-size chinook salmon held in the net pens was 85 percent of the estimate calculated for sublegal-size fish from the combined 1986 and 1987 data. By applying this factor to the 26 percent rate that we presented as a realistic, conservative estimate of total hooking mortality for sublegal-size chinook salmon, we derived a rate of 22.1 percent.

We think this rate is a realistic point estimation of total hooking mortality for legal-size chinook salmon because 1) it is consistent with the conclusion that mortality for legal-size fish is lower than that of sublegal-size fish, 2) it is consistent with the conclusion that there is some degree of additional delayed mortality above the 18.5 percent total mortality estimated from the pen studies, 3) it is based on an observed relationship between the hooking mortality of legal- and sublegal-size chinook salmon, and 4) it falls at the mid-point of the 18.5–26.4 percent minimum-maximum range we derived. We conclude that the hooking mortality of legal-size chinook salmon caught and released from commercial troll gear falls within the range of 18.5–26.4 percent, and that a reasonable point estimate is 22.1 percent.

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The Effects of Fish Trap Mesh Size on Reef Fish Catch off Southeastern Florida

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ABSTRACT—Catch and mesh selectivity of wire-meshed fish traps were tested for eleven different mesh sizes ranging from 13 × 13 mm (0.5 × 0.5″) to 76 × 152 mm (3 × 6″). A total of 1,810 fish (757 kg) representing 85 species and 28 families were captured during 330 trap hauls off southeastern Florida from December 1986 to July 1988. Mesh size significantly affected catches. The 1.5″ hexagonal mesh caught the most fish by number, weight, and value. Catches tended to decline as meshes got smaller or larger. Individual fish size increased with larger meshes. Laboratory mesh retention experiments showed relationships between mesh shape and size and individual retention for snapper (Lutjanidae), grouper (Serranidae), jack (Carangidae), porgy (Sparidae), and surgeonfish (Acanthuridae). These relationships may be used to predict the effect of mesh sizes on catch rates. Because mesh size and shape greatly influenced catchability, regulating mesh size may provide a useful basis for managing the commercial trap fishery.

Introduction

A concern exists that wire fish traps may be too effective and may damage reef fish stocks. Current regulations in the U.S. Gulf of Mexico and South Atlantic Federal waters allow minimum mesh sizes of 1 × 2″, 1.5″ hexagonal, and 1.5 × 1.5″. These mesh sizes retain snapper and grouper that are smaller than the minimum legal size limits and below the minimum size of first sexual maturity (Munro, 1983; Taylor and McMichael, 1983).

Sutherland and Harper (1983) and Taylor and McMichael (1983) reported that 38–50 percent of the fish captured in traps had no direct commercial importance. Noncommercial species and undersized commercial fishes incur injury and mortality from: 1) Attempting to escape from traps, 2) embolisms caused by changes in ambient pressure as traps are lifted to the surface, 3) stress and handling at the surface before release, and 4) predators such as moray eels which enter traps and prey on fishes before the traps are hauled (Sutherland and Harper, 1983; Taylor and McMichael, 1983). Lost traps (ghost traps) which continue to catch fish have also been a concern, although some evidence indicates that lost traps quickly become damaged and ineffective (Sutherland et al., 1983).

Determining the effects of mesh size on fish size and composition is important for fishery management. Adjusting trap mesh size can reduce the chances of overfishing and can optimize fishery resource production by reducing juvenile and bycatch mortality. Here we examine the effects of wire fish trap mesh size on the catch composition and size distribution of reef fishes off southeastern Florida.

The objectives of this research were to: 1) Document the size distribution of individuals and species caught by different mesh sizes, 2) determine the effects of different mesh sizes on catch of target and nontarget fishes, and 3) report the selectivity of meshes so that optimum mesh sizes can be determined for management purposes based on their capacity to reduce bycatch mortality and yet retain marketable fishes.

Previous studies of fish trap mesh selectivity may not be entirely applicable to the trap fishery in southeastern U.S. waters due to differences in species availability, abundance, and size of fish present. This study differs most importantly in that the sampled area had received relatively little trap fishing effort and that more mesh sizes were tested. Fish traps have been illegal in Florida state waters to a distance of 3 n.mi. (5.6 km) from shore since 1980, and in Federal waters at depths less than 100 feet (30 m) since 1983. Most previous studies of mesh selectivity have been conducted in heavily exploited areas outside the continental United States (Olsen et al., 1978; Stevenson and Stuart-Sharkey, 1980; Hartsuijker and Nicholson, 1981; Hartsuijker, 1982; Munro, 1983; Luckhurst and Ward, In press). In these locations detecting differences between meshes would be more difficult because larger individuals were more likely to be absent.

Methods

Field Methods

Fish traps constructed with different sizes of wire mesh were fished in depths of 7–40 m about 5–7 km east of Key Biscayne, Fla. Field studies consisted of two phases: December 1986 to July 1987 and October 1987 to July 1988. The first phase tested eight meshes (five square and three rectangular) measuring 0.5 × 0.5″ (13 × 13 mm), 1.5 × 1.5″ (38 × 38 mm), 1 × 2″ (25 × 51 mm), 2 × 2″ (51 × 51 mm), 2 × 3″ (51 × 76 mm), 3 × 3″

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(76 × 76 mm), 2 × 4″ (51 × 102 mm), and 4 × 4″ (102 × 102 mm). Measurements were from "knot to knot." The second phase added two rectangular and one hexagonal-shaped mesh: 1.5 × 3″ (38 × 76 mm), 3 × 6″ (76 × 152 mm), and 1.5 × 2.3″ (38 × 58 mm), respectively. Mesh sizes are referred to in English units for convenience. The hexagonal mesh is referred to as 1.5 ″ hexagonal. Mesh size characteristics and measurement conversions appear in Table 1.

All traps used vinyl-coated wire and were rectangular, measuring approximately 61 × 71 × 91 cm (2′ high × 2.3′ wide × 3′ long). Each trap had a single funnel entrance in one end that terminated in a 6 × 46 cm (2.5 × 18″) vertical opening. The top and bottom panels of the traps were constructed of the tested mesh. The side and end panels of all traps were constructed of 1 × 2″ (25 × 51 mm) vinyl-coated wire mesh to present the same silhouette and presumably the same amount of visual attractiveness to fish. This 1 × 2″ mesh was the second to smallest so that its presence did not affect results of other tested meshes. One trap was constructed entirely of 1 × 2″ wire mesh, but had all inside panels lined with the smallest tested mesh, 0.5 × 0.5″ galvanized hardware cloth. The 1 × 2″ mesh was considered the standard mesh based on its wide popularity and usage off southern Florida.

The traps were fished unbaited in trawls (strings) of four traps. Each trawl had traps attached at 50 m intervals to a 250 m groundline with a concrete or steel weight anchoring each end of the groundline. A subsurface or surface buoy was often attached to one end of each groundline to aid in relocation and retrieval. The traps were randomly attached to the groundline to prevent sampling bias and each set was fished under similar conditions of depth and bottom type to avoid confounding effects on mesh size. Soak times averaged 7 days but varied considerably (range 1–19 days) due to weather factors. Lost, stolen, or damaged fish traps were replaced or repaired as needed, and different traps of a given mesh size were rotated into the fishing schedule.

Table 1.—Dimensions of trap meshes used in field studies.

Shape	Width (inches)	Length (inches)	Area $(inches)^2$	Diagonal (inches)	Width (mm)	Length (mm)	Area (cm^2)	Diagonal (mm)
Square	0.5	0.5	0.25	0.71	12.7	12.7	1.6	18.0
Rectangular	1	2	2	2.24	25.4	50.8	12.9	56.8
Hexagonal	1.5	2.3	2.3	2.32	38.1	58.4	22.3	59.0
Square	1.5	1.5	2.25	2.12	38.1	38.1	14.5	53.9
Rectangular	1.5	3	4.5	3.35	38.1	76.2	29.0	85.2
Square	2	2	4	2.83	50.8	50.8	25.8	71.8
Rectangular	2	3	6	3.61	50.8	76.2	38.7	91.6
Rectangular	2	4	8	4.47	50.8	101.6	51.6	113.6
Square	3	3	9	4.24	76.2	76.2	58.1	107.8
Rectangular	3	6	18	6.71	76.2	152.4	116.1	170.4
Square	4	4	16	5.66	101.6	101.6	103.2	143.7

Table 2.—Summary of fish trap catch and effort data by mesh size and region.

Mesh size (inches)	Trap hauls (no.)	Total catch (no.)	Catch per haul (no.)	Total weight (kg)	Mean wt. per haul (kg)	Mean wt. per fish (kg)	Median wt. per fish (kg)	Total species (no.)
0.5 × 0.5″	28	322	11.50	50.46	1.80	0.16	0.08	35
1 × 2″	34	210	6.18	80.65	2.37	0.38	0.21	43
1.5 × 1.5″	30	259	8.63	128.13	4.27	0.50	0.22	41
1.5 Hex″	31	396	12.77	142.24	4.59	0.36	0.20	47
2 × 2″	27	153	5.67	53.98	2.00	0.35	0.24	33
1.5 × 3″	31	213	6.87	84.40	2.69	0.39	0.28	32
2 × 3″	31	76	2.45	73.71	2.38	0.97	0.38	25
2 × 4″	27	78	2.89	59.14	2.19	0.76	0.50	18
3 × 3″	29	67	2.31	40.88	1.41	0.61	0.45	15
4 × 4″	33	19	0.58	25.10	0.76	1.32	1.16	7
3 × 6″	29	17	0.59	18.89	0.65	1.11	0.80	7
Totals	330	1,810		757.58				85

The number of hauls for an adequate sample size was determined according to methods given by Bros and Cowell (1987). Mesh sizes added in phase II were fished more often in phase II to obtain comparable numbers of trap hauls.

Each captured fish was identified, weighed, and measured to the nearest millimeter of fork length. Total length, standard length, body depth, and body width were recorded for many individuals. Where possible, fish were released after measurements were made.

Economic Analysis

The effects of mesh size on the value of catches were analyzed based on voluntarily reported mean wholesale prices for each species by 30 seafood dealers from 6 Florida counties for May 1988 (Economics and Statistics Office, NMFS Southeast Fisheries Center, Miami, Fla., personal commun.). Wholesale price per pound was converted to mean price per gram and multiplied by the weight for each species from a standardized sample of 30 trap hauls per mesh size. Prices were adjusted according to fish size for some species as commonly done in the fishery. We assigned large individuals (> 5 pounds, 2.3 kg) the highest values, medium sizes (2–5 pounds, 0.9–2.3 kg) the lower range of values, and small sizes (< 2 pounds, 0.9 kg) a standard value of $0.50/pound ($1.10/kg).

Mesh Retention Experiments

The largest mesh that would retain a particular fish was determined during laboratory and field trials. Most of the fish used in laboratory studies were captured in fish traps during field studies, although some were obtained from other sources. Fish were tested by gently pushing them through various meshes (beginning with the largest and proceeding to smaller meshes) until they were retained. The hexagonal mesh was not tested because it easily became distorted during testing.

Table 3.—Percent catch composition by family. Families are listed according to decreasing percentages of 1980 weights. Data for 1980 are from the commercial trap fishery in Dade and Broward Counties (Sutherland and Harper, 1983). Data for 1987–88 are from southeastern Florida (Dade County) using 1 × 2″ mesh traps only. Sample size: 3,011 kg (5,984 fish) in 1980 and 757 kg (1,810 fish) in 1987–88.

	Weight		Numbers	
Family	1980	1987–88	1980	1987–88
Lutjanidae (snappers)	21.0	5.9	15.2	3.8
Serranidae (groupers)	10.0	21.0	0.9	2.4
Balistidae (leatherjackets)	10.0	17.0	14.8	22.4
Haemulidae (grunts)	9.1	17.0	19.2	31.4
Pomacanthidae (angelfishes)	7.5	3.7	4.7	1.9
Sparidae (porgies)	7.4	0.8	7.8	1.0
Labridae (wrasses)	6.9	1.7	3.2	1.9
Acanthuridae (surgeonfishes)	6.7	6.7	7.6	11.9
Scaridae (parrotfishes)	4.9	3.7	4.3	3.8
Ostraciidae (boxfishes)	3.3	1.1	5.1	1.4
Carangidae (jacks)	3.2	2.5	2.5	2.4
Pricanthidae (bigeyes)	2.2	0.0	3.1	0.0
Diodontidae (porcupinefishes)	1.5	1.6	3.2	3.3
Scorpaenidae (scorpionfishes)	1.4	2.0	1.8	2.4
Muraenidae (morays)	1.3	6.6	0.4	1.4
Holocentridae (squirrelfishes)	1.1	1.3	1.7	2.4

Results

Catches

Fish trap catch and effort data were summarized for field studies (Table 2). A total of 1,810 fish, representing 85 species in 28 families and weighing 757 kg, were captured during 330 trap hauls. The relative percent contribution of various families to total catch was compared with previous data from commercial trap catches for southeastern Florida (Table 3). This comparison reflects only data from 1 × 2″ meshed traps, the predominant commercially used trap in 1980. A 1979–80 survey of commercial trap catches off Dade and Broward counties showed that snapper, grouper, triggerfish, and grunts, in decreasing order of abundance, dominated commercial trap catches (Sutherland and Harper, 1983). The 1987–88 catches were dominated by grouper, triggerfish, and grunts, with snapper ranking 6th in weight.

In the current study, mean catches ranged from a low of 0.58 fish/haul for a 4 × 4″ mesh to 12.77 fish/haul for the 1.5″ hexagonal mesh (Tables 2, 4; Fig. 1). With the exception of the 0.5 × 0.5″ mesh (which had the second highest average catch in numbers) the average number of fish per haul tended to decline with meshes larger or smaller than 1.5″ hexagonal. The total number of species caught in larger mesh traps was considerably less than with smaller mesh (Table 2).

Mean total weight per haul tended to decline with meshes larger or smaller than 1.5″ hexagonal, ranging from a low of 0.65 kg for a 3 × 6″ mesh to a high of 4.59 kg for the 1.5 ″ hexagonal mesh (Tables 2, 5; Fig. 1).

Mean weight per fish tended to increase with mesh size, especially for

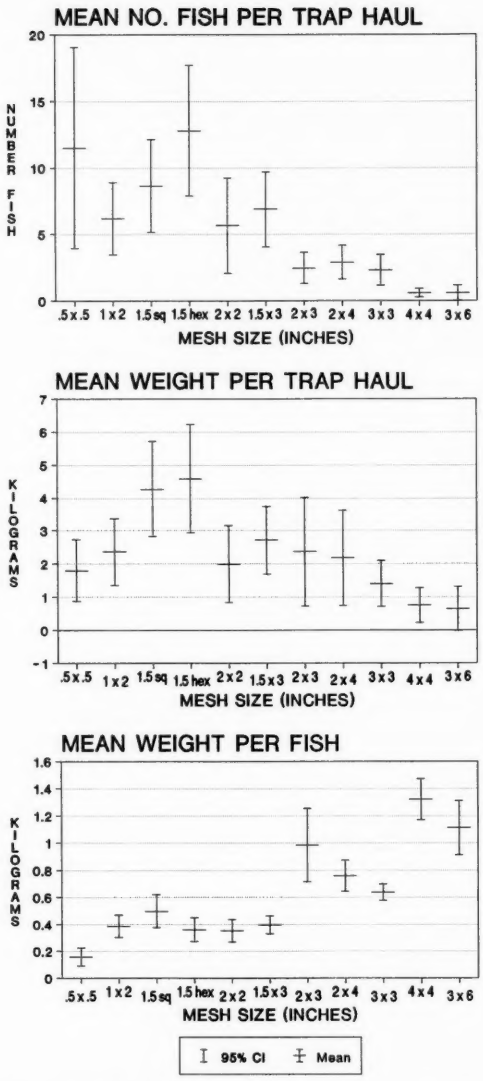


Figure 1.—Effects of mesh size on fish trap catches. Bars show means and 95 percent confidence intervals. Sample sizes are in Table 2.

Table 4.—Weight (g) of fish caught by various meshes off southeastern Florida between December 1986 and July 1988.

Species	Weight of fish caught (g) by mesh size (inches)[1]											
	0.5×0.5	1×2	1.5×1.5	1.5 Hex	2×2	1.5×3	2×3	2×4	3×3	4×4	3×6	Total
Acanthurus behianus	595	1,905	100	2,810	724	1,705	225					8,064
Acanthurus chirurgus	245	1,486	4,553	3,315	7,607	8,330	3,893		6,976			36,405
Acanthurus coeruleus		2,005	5,555	4,791	865	7,039	1,245		2,860			24,360
Aluterus schoepfi		9,766		4,510	475	11,072	4,425	17,206	2,175	4,063	450	54,142
Aluterus scriptus		507	600	675		605						2,387
Anisotremus surinamensis		2,910				1,252			1,020			5,182
Anisotremus virginicus	450	2,019	2,289	5,915	1,505	4,645						16,823
Aulostomus maculatus	200											200
Balistes capriscus			425	970	377	2,057	391					4,220
Balistes vetula									1,482			1,482
Calamus bajonado			475		495		1,220					2,190
Calamus calamus		625			309	970	1,155					3,059
Calamus proridens						765	380	400				1,545
Cantherhines macrocerus					780							780
Cantherhines pullus	99	128	375	680								1,282
Canthidermis sufflamen	145											145
Caranx bartholomaei		675	21,010	16,805	320	6,539		1,425		6,500		53,274
Caranx crysos			975	375		695	784					2,829
Caranx latus	121	900										1,021
Caranx ruber			1,040	380								1,420
Chaetodipterus faber					405					1,955		2,360
Chaetodon capistratus	100	125	500	145	47							917
Chaetodon ocellatus	125	235	1,755	800	669	370						3,954
Chaetodon sedentarius		175		435								610
Chaetodon striatus				50	187							237
Chilomycterus schoepfi							329					329
Dasyatis americana			2,140									2,140
Diodon holocanthus	137	1,326	770	1,025	879	922						5,059
Epinephelus morio		1,685	4,200	3,895	919							10,699
Epinephelus sp.		1,600										1,600
Epinephelus striatus			1,380									1,380
Equetus acuminatus	97		113									210
Ginglyostoma cirratum		3,600	2,920	9,380			13,000					28,900
Gymnothorax funebris	6,500	3,780		2,550	9,240		11,700					33,770
Gymnothorax moringa		1,574										1,574
Haemulon album			415					798				1,213
Haemulon aurolineatum	13,411	200		1,337								14,948
Haemulon carbonarium				250								250
Haemulon flavolineatum	1,750	1,820	3,055	6,765	201							13,591
Haemulon parrai	645		615	2,738	361	1,998	485	400				7,242
Haemulon plumieri	4,861	6,664	5,080	11,718	8,471	3,435						40,229
Haemulon sciurus	387		1,220	3,117								4,724
Halichoeres bivittatus	46											46
Holacanthus bermudensis			1,575	5,860	1,174	1,150		7,176	10,848	3,800	7,480	39,063
Holacanthus ciliaris		400			248	745		540	317			2,250
Holacanthus tricolor	19		740	500	260	250						1,769
Holocentrus ascensionis	210	912	580		196							1,898
Holocentrus rufus		175	1,180	612								1,967
Kyphosus sectatrix				800								800
Lachnolaimus maiximus	4,435	1,340	6,730	3,892	2,979	2,970	450	3,322	2,080	1,400		29,598
Lactophrys bicaudalis				400	120							520
Lactophrys polygonia							111	1,241	510			1,862
Lactophrys quadricornis			300	1,015		3,111	1,896	1,348	580		1,206	9,456
Lactophrys trigonus											591	591
Lactophrys triqueter		900				485	372	207				1,964
Lutjanus analis	1,573	3,020	12,200	6,241		5,545	1,460	11,900	2,700			44,639
Lutjanus apodus				2,660								2,660
Lutjanus cyanopterus						7,250		6,500				13,750
Lutjanus griseus		1,255	1,520	665								3,440
Lutjanus jocu						766						766
Lutjanus synagris		104	2,100	1,723			105					4,032
Monacanthus hispidus	587	3,462	2,291	1,975	2,948	990	1,510		250			14,013
Muiloidichthys martinicus	417											417
Mycteroperca bonaci	7,350			5,800			8,750				7,850	29,750
Mycteroperca microlepis		13,480		4,650								18,130
Ocyurus chrysurus		395	1,375	4,880	1,680							8,330
Pomacanthus arcuatus		980	1,200	3,755	2,765	2,285	1,257	3,565	4,479	5,680		25,966
Pomacanthus paru		1,572						1,293		1,700	810	5,375
Priacanthus arenatus					285		336					621
Prionotus roseus	38											38
Pseudupeneus maculatus	2,041	428		200		255						2,924
Rachycentron canadum		1,450										1,450
Scarus coeruleus				975		2,625						3,600
Scarus taenipterus	585											585
Scorpaena plumieri		1,649	400	270				605			500	3,424
Seriola dumerili				8,500								8,500
Seriola rivoliana		450	282		540	340						1,612
Sparisom chrysopterum	850	2,197	2,008	300	480	1,879						7,714
Sparisoma aurofrenatum	160	200										360
Sparisoma sp.	500											500
Sparisoma viride	350	570	405	1,140	5,467	460	4,520	520	700			14,132
Sphoeroides spengleri	724											724
Sphyraena barracuda	620		31,680				13,710		3,900			49,910
Umbrina coroides	90											90
Urolophus jamaicensis								695				695
Total weight (g)	50,463	80,649	128,126	142,244	53,978	83,505	73,708	59,141	40,875	25,098	18,887	756,674
											Count	85
Number of samples	28	34	30	31	27	31	31	27	29	33	29	

[1]The following five partially decomposed fish were caught in the indicated meshes but were not weighed: *Gymnothorax funebris* (1.5 × 1.5") *Sparisoma viride* (2 × 3"); *Holacanthus bermudensis*, *Pomacanthus arcuatus*, and *Sphyraena barracuda* (3 × 3").

meshes 2 × 3″ and larger (Fig. 1, 2; Table 2). The average weight per fish ranged from a low of 0.16 kg for a 0.5 × 0.5″ mesh to a high of 1.3 kg for the 4 × 4″ mesh. Because the weight/frequency distributions were strongly skewed (Fig. 2), median fish size was also examined. Median size increased with mesh size, ranging from a low of 0.08 kg for a 0.5 × 0.5″ mesh to a maximum of 1.16 kg for a 4 × 4″ mesh (Table 2, Fig. 2). Median weights of fish remained relatively constant (0.20–0.28 kg) for five smaller meshes ranging in size from 1 × 2″ to 1.5 × 3″. Median weights of fish caught in traps with meshes of 2 × 3″ or larger were about two to five times higher (0.38–1.3 kg) than those from the five smallest mesh sizes.

The effect of mesh size on individual weight was determined using a one-way analysis of variance on log-transformed data. The null hypothesis of no difference between mesh sizes was rejected ($F = 84.50$; $df = 10, 1794$; $p < 0.05$). An a posteriori least-significant difference test (LSD test) compared all possible pairs of mean weights by mesh size. Forty-five of the 55 paired mean weights differed significantly ($p < 0.05$, LSD test) by mesh size (Table 6). The ten paired catches that did not differ significantly tended to be for adjacent mesh size.

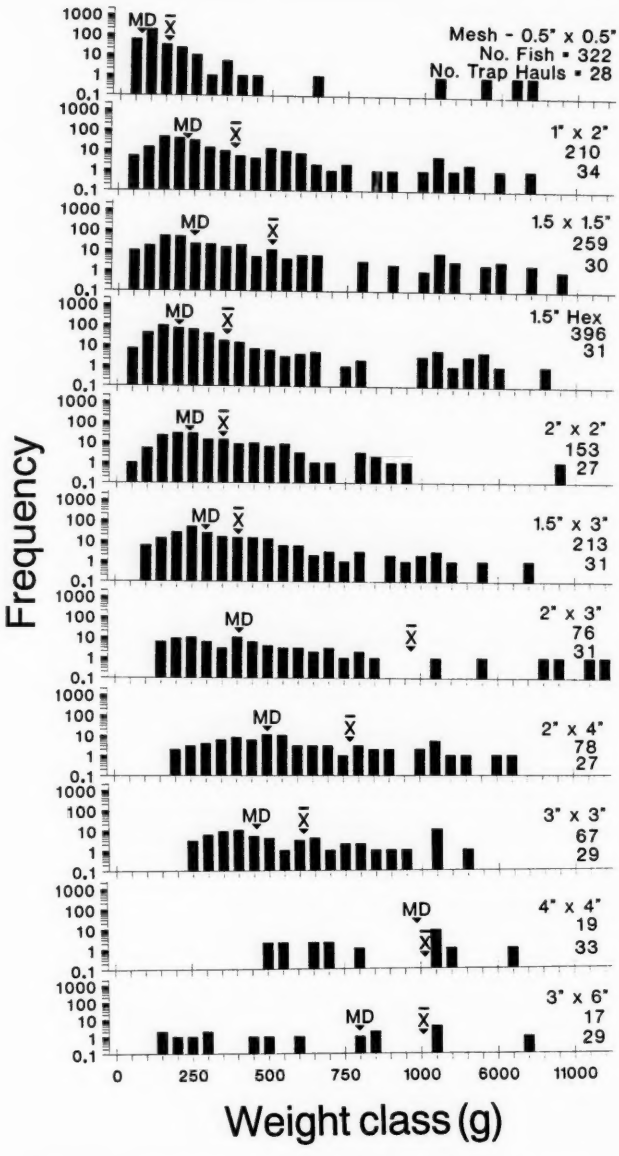


Figure 2.—Weight-frequency of trapped fish by mesh size. Fish weighing less than 1,000 g were grouped into 50 g intervals. Fish weighing more than 1,000 g were grouped into 1,000 g intervals. X is mean weight, MD is median weight.

Economics

The value of catches was examined based on market categories (Tables 7, 8). Primary commercial species had the highest market value and included snappers (Lutjanidae), groupers (Serranidae), and hogfish, *Lachnolaimus maximus*. Secondary commercial species had about half the market value of primary commercial species and included grunts (Haemulidae), porgies (Sparidae), triggerfishes (Balistidae), and some jacks, *Seriola* sp. Other species had limited or no market value. Primary commercial species were the major component of total value for most meshes although the relative contribution varied considerably (Fig. 3).

The estimated commercial wholesale value, based on a standardized sample of 30 trap hauls per mesh, ranged from $0.41/haul for the 4 × 4″ mesh to $5.42/haul for the 1.5″ hexagonal mesh (Fig. 3). Catch value, although variable, tended to decrease for meshes smaller and larger than the 1.5″ hexagonal mesh and was roughly correlated to total numbers and weight per haul (Fig. 4).

Table 5.—Species and number of fish trapped by mesh size off southeastern Florida between December 1986 and July 1988.

Species	Number of fish trapped by mesh size (inches)[1]											
	0.5×0.5	1×2	1.5×1.5	1.5 Hex	2×2	1.5×3	2×3	2×4	3×3	4×4	3×6	Total
Acanthurus behianus	3	10	1	15	3	7	1					40
Acanthurus chirurgus	1	6	13	13	21	28	10		17			109
Acanthurus coeruleus		9	18	20	4	31	5		9			96
Aluterus schoepfi		18		10	1	21	8	36	4	6	1	105
Aluterus scriptus		1	1	2		2						6
Anisotremus surinamensis		6				3			1			10
Anisotremus virginicus	1	7	8	25	5	18						64
Aulostomus maculatus	1											1
Balistes capriscus			3	1	2	6	1					13
Balistes vetula									2			2
Calamus bajonado			1		1		2					4
Calamus calamus		2			1	3	4					10
Calamus proridens						2	1	1				4
Cantherhines macrocerus				1								1
Cantherhines pullus	1	1	3	7								12
Canthidermis sufflamen	1											1
Caranx bartholomaei		2	21	9	1	2		2		1		38
Caranx crysos			5	1		2	1					9
Caranx latus	1	2										3
Caranx ruber			3	1								4
Chaetodipterus faber					1					2		3
Chaetodon capistratus	1	3	11	2	1							18
Chaetodon ocellatus	1	3	15	10	6	4						39
Chaetodon sedentarius		1		7								8
Chaetodon striatus				1	2							3
Chilomycterus schoepfi							1					1
Dasyatis americana			1									1
Diodon holocanthus	1	7	4	5	4	6						27
Epinephelus morio		2	3	2	2							9
Epinephelus sp.		1										1
Epinephelus striatus			1									1
Equetus acuminatus	2		1									3
Ginglyostoma cirratum		2	2	2			1					7
Gymnothorax funebris	1	1	1	1	1		1					6
Gymnothorax moringa		2										2
Haemulon album			1						1			2
Haemulon aurolineatum	179	2		15								196
Haemulon carbonarium				1								1
Haemulon flavolineatum	17	15	21	52	1							106
Haemulon parrai	2		2	9	1	7	2	1				24
Haemulon plumieri	38	36	26	64	40	13						217
Haemulon sciurus	3		7	17								27
Halichoeres bivittatus	1											1
Holacanthus bermudensis			3	6	2	1		8	12	3	6	41
Holacanthus ciliaris		1			1	2		1	1			6
Holacanthus tricolor	1		4	2	1	1						9
Holocentrus ascensionis	1	4	2		1							8
Holocentrus rufus		1	7	4								12
Kyphosus sectatrix				1								1
Lachnolaimus maximus	2	4	12	13	6	6	1	4	3	1		52
Lactophrys bicaudalis				1	1							2
Lactophrys polygonia							1	3	2			6
Lactophrys quadricornis			1	4		13	9	5	2		6	40
Lactophrys trigonus											1	1
Lactophrys triqueter		3				1	1	1				6
Lutjanus analis	2	1	6	4		9	2	3	2			29
Lutjanus apodus				10								10
Lutjanus cyanopterus						1		1				2
Lutjanus griseus		4	2	3								9
Lutjanus jocu						1						1
Lutjanus synagris		1	15	9			1					26
Monacanthus hispidus	4	28	14	12	21	8	8		1			96
Mulloidichthys martinicus	2											2
Mycteroperca bonaci	1			1			1				1	4
Mycteroperca microlepis		2		1								3
Ocyurus chrysurus		2	5	21	4							32
Pomacanthus arcuatus		1	2	5	4	4	3	5	8	4		36
Pomacanthus paru		2						2		2	1	7
Priacanthus arenatus					1		1					2
Prionotus roseus	1											1
Pseudupeneus maculatus	15	2		1		1						19
Rachycentron canadum		1										1
Scarus coeruleus				1		4						5
Scarus taenipterus	3											3
Scorpaena plumieri		5	1	1				2			1	10
Seriola dumerili				1								1
Seriola rivoliana		1	1		1	1						4
Sparisom chrysopterum	4	6	5	1	1	4						21
Sparisoma aurofrenatum	3	1										4
Sparisoma sp.	5											5
Sparisoma viride	1	1	1	2	10	1	8	1	1			26
Sphoeroides spengleri	20											20
Sphyraena barracuda	1		5				2		2			10
Umbrina coroides	1											1
Urolophus jamaicensis								1				1
Total number	101	210	259	396	153	213	76	78	67	19	17	1,810
Number of samples	28	34	30	31	27	31	31	27	29	33	29	

[1]The number of species reported differs from Table 4 because some fish were counted but not weighted.

Table 6.—Differences in mean fish weight as a function of mesh size.

Mesh size (inches)	Mesh size (inches)										
	0.5 × 0.5	1 × 2	1.5 × 1.5	1.5 Hex	2 × 2	1.5 × 3	2 × 3	2 × 4	3 × 3	4 × 4	3 × 6
0.5×0.5											
1×2	*[1]										
1.5×1.5	*	*									
1.5 Hex	*	n[2]	n								
2×2	*	*	n	n							
1.5×3	*	*	*	*	n						
2×3	*	*	*	*	*	*					
2×4	*	*	*	*	*	*	*				
3×3	*	*	*	*	*	*	n	n			
4×4	*	*	*	*	*	*	*	*	*		
3×6	*	*	*	*	*	*	n	n	n	*	

[1]* = significant difference ($p < 0.05$, LSD test).
[2]n = no significant difference ($p > 0.05$).

Table 7.—Wholesale market value, based on voluntary reports by 30 dealers from six Florida counties for May 1988.

Category	Number of dealers reporting	Price ($/lb)		
		Mean	Min.	Max.
Amberjack	13	0.38	0.20	0.50
Angelfish	1	0.15	0.15	0.15
Baitfish	9	0.24	0.05	0.60
Grouper, black	21	2.05	1.40	2.40
Grouper, gag	15	1.96	1.40	2.30
Grouper, Nassau	5	1.65	1.45	2.00
Grouper, red	19	1.63	1.15	2.20
Grouper, scamp	13	2.21	1.70	2.80
Grouper, snowy	8	1.76	1.45	2.20
Grouper, Warsaw	6	1.30	0.90	1.90
Grouper, yellowedge	3	1.83	1.60	2.00
Grouper, yellowfin	4	1.85	1.60	2.00
Grouper, other, mixed	5	1.78	1.65	2.20
Grunts	12	0.36	0.20	0.60
Hogfish	6	1.33	1.00	1.50
Jacks, crevalle	13	0.29	0.20	0.70
Rays	2	0.06	0.05	0.06
Snapper, lane	8	1.04	0.65	1.50
Snapper, mangrove	17	1.44	1.00	2.25
Snapper, mutton	10	1.77	1.50	2.05
Snapper, yellowtail	8	1.86	1.50	2.40
Snapper, other, mixed	4	1.99	1.80	2.10
Triggerfish	8	0.71	0.50	1.05
Porgy (white snapper)	11	0.55	0.30	0.80
Misc. food fish	11	0.29	0.20	0.35

Mesh Retention

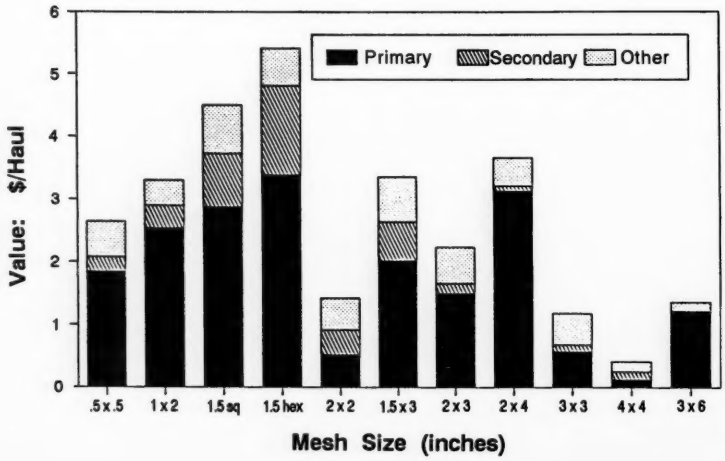
A total of 758 fish among 62 species were tested to determine their ability to escape mesh of different sizes. The largest mesh able to retain a fish was determined for the six most common families (Table 9). The size of retained fish for each family was related to mesh size and shape. Because of biological variability, different fish of the same species and length may or may not be retained by a particular mesh. Because area changes exponentially with the liner mesh dimensions, we examined the relative effects of mesh size on numbers, weight, and value per haul based on the area of the mesh opening (Fig. 4).

Table 8.—Value of catches ($) by mesh size and species, standarized for 30 trap hauls.

Species	P,S,O	Value ($) by mesh size (inches) 0.5×0.5	1×2	1.5×1.5	1.5 Hex	2×2	1.5×3	2×3	2×4	3×3	4×4	3×6	Total
Acanthurus behianus	O	0.41	1.07	0.06	1.74	0.51	1.05	0.14	0	0	0	0	$4.98
Acanthurus chirurgus	O	0.17	0.84	2.91	2.05	5.4	5.15	2.41	0	4.61	0	0	$23.54
Acanthurus coeruleus	O	0	1.13	3.55	2.96	0.61	4.35	0.77	0	1.89	0	0	$15.26
Aluterus schoepfi	O	0	2.85	0	1.44	0.17	3.54	1.41	6.32	0.74	1.22	0.15	$17.84
Aluterus scriptus	O	0	0.15	0.2	0.22	0	0.19	0	0	0	0	0	$0.76
Anisotremus surinamensis	S	0	2.04	0	0	0	0.96	0	0	0.84	0	0	$3.84
Anisotremus virginicus	S	0.38	1.41	1.82	4.54	1.33	3.56	0	0	0	0	0	$13.04
Aulostomus maculatus	O	0.07	0	0	0	0	0	0	0	0	0	0	$0.07
Balistes capriscus	S	0	0	0.66	1.47	0.66	3.11	0.59	0	0	0	0	$6.49
Balistes vetula	S	0	0	0	0	0	0	0	0	2.4	0	0	$2.40
Calamus bajonado	S	0	0	0.58	0	0.67	0	1.43	0	0	0	0	$2.68
Calamus calamus	S	0	0.67	0	0	0.42	1.14	1.35	0	0	0	0	$3.58
Calamus proridens	S	0	0	0	0	0	0.9	0.45	0.54	0	0	0	$1.89
Cantherhines macrocerus	O	0	0	0	0	0.29	0	0	0	0	0	0	$0.29
Cantherhines pullus	O	0.04	0.04	0.12	0.22	0	0	0	0	0	0	0	$0.42
Canthidermis sufflamen	S	0.24	0	0	0	0	0	0	0	0	0	0	$0.24
Caranx bartholomaei	S	0	0.38	13.42	10.39	0.23	4.04	0	1.01	0	3.77	0	$33.24
Caranx crysos	S	0	0	0.62	0.23	0	0.43	0.48	0	0	0	0	$1.76
Caranx latus	O	0.08	0.51	0	0	0	0	0	0	0	0	0	$0.59
Caranx ruber	O	0	0	0.66	0.24	0	0	0	0	0	0	0	$0.90
Chaetodipterus faber	O	0	0	0	0	0.06	0	0	0	0	0.23	0	$0.29
Chaetodon capistratus	O	0.01	0.01	0.07	0.02	0.01	0	0	0	0	0	0	$0.12
Chaetodon ocellatus	O	0.02	0.03	0.23	0.1	0.1	0.05	0	0	0	0	0	$0.53
Chaetodon sedentarius	O	0	0.02	0	0.06	0	0	0	0	0	0	0	$0.08
Chaetodon striatus	O	0	0	0	0.01	0.03	0	0	0	0	0	0	$0.04
Chilomycterus schoepfi	O	0	0	0	0	0	0	0.04	0	0	0	0	$0.04
Dasyatis americana	O	0	0	0.28	0	0	0	0	0	0	0	0	$0.28
Diodon holocanthus	O	0.02	0.15	0.1	0.13	0.13	0.12	0	0	0	0	0	$ 0.65
Epinephelus morio	P	0	0	0	11.47	0	0	0	0	0	0	0	$11.47
E. morio, medium	P	0	1.86	7.59	0	0	0	0	0	0	0	0	$9.45
E. morio, small	P	0	0.41	0	0.52	0.92	0	0	0	0	0	0	$1.85
Epinephelus sp.	P	0	0	0	0	0	0	0	0	0	0	0	$0.00
E. sp., medium	P	0	2.77	0	0	0	0	0	0	0	0	0	$2.77
Epinephelus striatus	P	0	0	5.02	0	0	0	0	0	0	0	0	$5.02
Equetus acuminatus	O	0.01	0	0.01	0	0	0	0	0	0	0	0	$0.02
Ginglyostoma cirratum	O	0	0.42	0.39	1.2	0	0	1.66	0	0	0	0	$3.67
Gymnothorax funebris	O	0.92	0.44	0	0.33	1.36	0	1.5	0	0	0	0	$4.55
Gymnothorax moringa	O	0	0.18	0	0	0	0	0	0	0	0	0	$0.18
Haemulon album	S	0	0	0.33	0	0	0	0	0.7	0	0	0	$1.03
Haemulon aurolineatum	O	11.39	0.14	0	1.03	0	0	0	0	0	0	0	$12.56
Haemulon carbonarium	S	0	0	0	0.19	0	0	0	0	0	0	0	$0.19
Haemulon flavolineatum	S	1.49	1.27	2.42	5.19	0.18	0	0	0	0	0	0	$10.55
Haemulon parrai	S	0.55	0	0.49	2.1	0.32	1.53	0.37	0.35	0	0	0	$5.71
Haemulon plumieri	S	4.13	4.66	4.03	8.99	7.46	2.64	0	0	0	0	0	$31.91
Haemulon sciurus	S	0.33	0	0.97	2.39	0	0	0	0	0	0	0	$3.69
Halichoeres bivittatus	O	0.01	0	0	0	0	0	0	0	0	0	0	$0.01
Holacanthus bermudensis	O	0	0	0.52	1.87	0.43	0.37	0	2.63	3.71	1.14	2.56	$13.23
Holacanthus ciliaris	O	0	0.12	0	0	0.09	0.24	0	0.2	0.11	0	0	$0.76
Holacanthus tricolor	O	0.01	0	0.24	0.16	0.1	0.08	0	0	0	0	0	$0.59
Holocentrus ascensionis	O	0.12	0.43	0.31	0	0.12	0	0	0	0	0	0	$0.98

Continued on next page.

Figure 3.—Relative catch value by mesh size.



Discussion

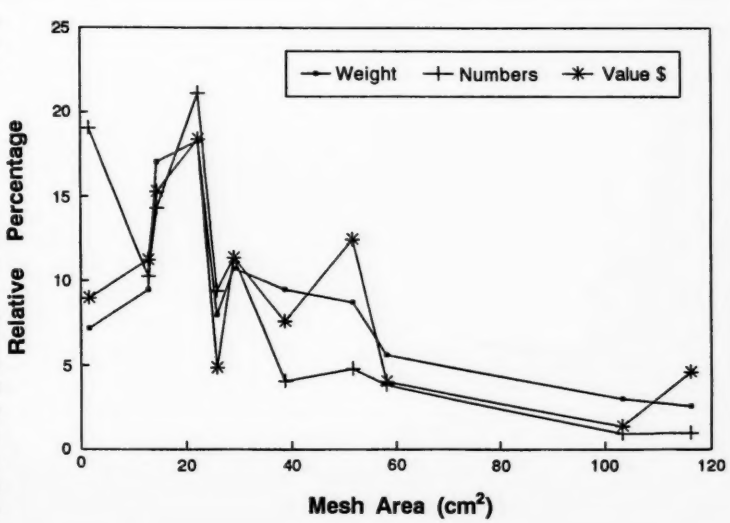
The ability of a trap to catch fish depends on the availability of fish in the area, the willingness of a fish to enter a trap, and the ability of a fish to escape a trap. In this study, differences in catch between mesh sizes show the willingness of fish to enter traps and their ability to escape based on mesh size. We assume availability of fishes was the same for all mesh sizes tested.

Table 8.—Continued.

Species	P,S,O	Value ($) by mesh size (inches) 0.5×0.5	1×2	1.5×1.5	1.5 Hex	2×2	1.5×3	2×3	2×4	3×3	4×4	3×6	Total
Holocentrus rufus	O	0	0.08	0.62	0.31	0	0	0	0	0	0	0	$1.01
Kyphosus sectatrix	O	0	0	0	0.41	0	0	0	0	0	0	0	$0.41
Lachnolaimus maiximus	P	13.92	3.46	19.72	11.03	9.7	8.42	1.27	10.81	6.3	3.73	0	$88.36
Lactophrys bicaudalis	O	0	0	0	0.25	0.08	0	0	0	0	0	0	$0.33
Lactophrys polygonia	O	0	0	0	0	0	0	0.07	0.88	0.34	0	0	$1.29
Lactophrys quadricornis	O	0	0	0.19	0.63	0	1.92	1.17	0.96	0.38	0	0.8	$6.05
Lactophrys trigonus	O	0	0	0	0	0	0	0	0	0	0	0.39	$0.39
Lactophrys triqueter	O	0	0.51	0	0	0	0.3	0.23	0.15	0	0	0	$1.19
Lutjanus analis	P	5.1	10.39	44.41	22.22	0	15.58	5.51	51.55	10.89	0	0	$165.65
L. analis medium	P	0.74	0	1.59	0.67	0	2.5	0	0	0	0	0	$5.50
L. analis, small	P	0	0	0	0	0	0.1	0	0	0	0	0	$0.10
Lutjanus apodus	P	0	0	0	0	0	0	0	0	0	0	0	$0.00
L. apodus, medium	P	0	0	0	1.58	0	0	0	0	0	0	0	$1.58
L. apodus, small	P	0	0	0	2.05	0	0	0	0	0	0	0	$2.05
Lutjanus cyanopterus	P	0	0	0	0	0	30.75	0	31.66	0	0	0	$62.41
Lutjanus griseus	P	0	1.33	3.71	0	0	0	0	0	0	0	0	$5.04
L. griseus, medium	P	0	0.49	0.59	0	0	0	0	0	0	0	0	$1.08
L. griseus, small	P	0	0.34	0	0.55	0	0	0	0	0	0	0	$0.89
Lutjanus jocu	P	0	0	0	0	0	3.25	0	0	0	0	0	$3.25
Lutjanus synagris	P	0	0	0	0	0	0	0	0	0	0	0	$0.00
L. synagris, small	P	0	0.08	1.8	1.43	0	0	0.09	0	0	0	0	$3.40
Monacanthus hispidus	O	0.08	0.4	0.3	0.25	0.43	0.13	0.19	0	0.03	0	0	$1.81
Mulloidichthys martinicu	O	0.29	0	0	0	0	0	0	0	0	0	0	$0.29
Mycteroperca bonaci	P	35.56	0	0	25.35	0	0	38.24	0	0	0	36.67	$135.82
Mycteroperca microlepis	P	0	51.35	0	19.43	0	0	0	0	0	0	0	$70.78
Ocyurus chrysurus	P	0	0	0	0	2.34	0	0	0	0	0	0	$2.34
O. chrysurus, medium	P	0	0	0.7	0.65	2.79	0	0	0	0	0	0	$4.14
O. chrysurus, small	P	0	0.38	1.13	4.77	0	0	0	0	0	0	0	$6.28
Pomacanthus arcuatus	O	0	0.29	0.4	1.2	1.01	0.73	0.4	1.31	1.53	1.71	0	$8.58
Pomacanthus paru	O	0	0.46	0	0	0	0	0	0.47	0	0.51	0.28	$1.72
Priacanthus arenatus	O	0	0	0	0	0.17	0	0.17	0	0	0	0	$0.34
Prionotus roseus	O	0.01	0	0	0	0	0	0	0	0	0	0	$0.01
Pseudupeneus maculatus	O	1.4	0.24	0	0.12	0	0.16	0	0	0	0	0	$ 1.92
Rachycentron canadum	P	0	3.38	0	0	0	0	0	0	0	0	0	$ 3.38
Scarus coeruleus	O	0	0	0	0.6	0	1.62	0	0	0	0	0	$2.22
Scarus taenipterus	O	0.4	0	0	0	0	0	0	0	0	0	0	$0.40
Scorpaena plumieri	O	0	0	0	0	0	0	0	0	0	0	0	$0.00
Seriola dumerili	S	0	0	0	6.89	0	0	0	0	0	0	0	$6.89
Seriola rivoliana	S	0	0.33	0.24	0	0.5	0.28	0	0	0	0	0	$1.35
Sparisom chrysopterum	O	0.58	1.24	1.28	0.19	0.34	1.16	0	0	0	0	0	$4.79
Sparisoma aurofrenatum	O	0.11	0.11	0	0	0	0	0	0	0	0	0	$0.22
Sparisoma sp.	O	0.34	0	0	0	0	0	0	0	0	0	0	$0.34
Sparisoma viride	O	0.24	0.32	0.26	0.7	3.88	0.28	2.79	0.37	0.46	0	0	$9.30
Sphoeroides spengleri	O	0	0	0	0	0	0	0	0	0	0	0	$0.00
Sphyraena barracuda	O	0.22	0	10.47	0	0	0	4.38	0	1.33	0	0	$16.40
Umbrina coroides	O	0.01	0	0	0	0	0	0	0	0	0	0	$0.01
Urolophus jamaicensis	O	0	0	0	0	0	0	0	0.1	0	0	0	$0.10
Total value		$79.40	$99.18	$135.01	$162.54	$42.84	$100.63	$67.11	$110.01	$35.56	$12.31	$40.85	$885.44

[1]Commercial classification: P = primary, S = secondary, O = other.

Figure 4.—Relative effects of mesh area on mean total weight, mean total numbers, and mean total value per haul.



Comparing our results to a study of the 1979–80 commercial trap fishery off Dade and Broward Counties (Sutherland and Harper, 1983), we found commercial species comprised 66 percent by weight and 64 percent by number vs. 77 percent by weight and 62 percent by number in 1980. We averaged 2.4 kg and 6.2 fish per haul compared to 5.6 kg and 11.1 fish per haul in the 1980 study. Catches with the 1.5″ hexagonal mesh were more

Table 9.—Fork length (cm) of fishes retained by different trap meshes.

Family and mesh size	Fork Length (cm)																															Total retained
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	
Snapper																																				152
1×2″						1			1	6	2	11	24	23	4	2		1																		75
1.5×1.5″									1	4	2	4	7	6	1	3																				28
2×2″											1		2	2	3	6	7	4	1		1															27
2×3″																		1		4	1	1		2	1			1								11
>3×3″																										1	1		3	1	3	1			1	11
Grouper																																				26
1×2″														4																						4
2×2″																2		2	2				1													7
2×3″																1			1	2		2			2	1										9
>3×3″																												2			2		1	1		6
Grunts																																				250
0.5×0.5″			3	5	3	6	6																													23
1×2″						3	13	18	16	12	6	2	2																							72
1.5×1.5″						2	6	12	9	4	2		1																							36
2×2″							3	2	3	11	24	16	7	9	3																					78
2×3″								1		2	5	5	4	6	2	7	3	2	2	1	1															41
Jacks																																				59
1×2″									3	3	2	5	5	2	3	1																				24
1.5×1.5″									6	3	2	5	4	2	2	1																				25
2×2″																	2			3																5
2×3″																	2			3																5
Porgy																																				34
1×2″				1			2	1	3			1																								8
1.5×1.5″				1			1		1			1																								4
1.5×3″											2				1		1																			4
2×3″											2	2	5	1																						10
>3×3″												1		1		2	1	3																		8
Surgeonfish																																				101
1×2″								3	2	4	8	2	3	1		1																				24
1.5×1.5″						1		3	5	7	8	8	8	3	5	4	1																			53
2×2″											2	5	2	1	3	7	1	2																		23
2×3″																1																				1
>3×3″																																				0

similar to those reported during the 1980 study, averaging 4.6 kg and 12.8 individuals per haul. Differences in the present and earlier study partially reflect differences in trap designs, area fished, and method of fishing. In this study we tended to sample in shallower water with smaller traps which may account for the differences in catch data. Other studies have shown that catches are significantly affected by the type of funnel opening, trap size, trap shape, bait and other variables (Luckhurst and Ward, In press).

Selectivity

A concern of commercial fishermen is that fish will not enter traps with larger sized meshes because these traps are less visually distinctive. We found that commercial species will enter traps with a wide variety of mesh sizes. The walls of all traps were constructed with 1 × 2″ wire mesh so that they presented the same visual silhouette and did not bias catches due to differential attraction. Luckhurst and Ward (In press) noted mesh selectivity could be biased by fish attraction to different trap silhouettes. The darker trap silhouette created by the 0.5 × 0.5″ mesh lining a 1 × 2″ mesh was apparently not more attractive to larger fish than were the other unlined traps which had a standard 1 × 2″ wall mesh. Although the 0.5 × 0.5″ trap had one of the highest catch rates by numbers (11.5 fish/haul), the mean weight/haul (1.8 kg) was similar to those reported for much larger meshes (Fig. 1, Table 2). The high numbers in the 0.5 × 0.5″ mesh are mainly accounted for by many small fishes, such as the tomtate, *Haemulon aurolineatum*, that could escape all larger mesh sizes (Table 4). Other size-related behavioral responses that affect recruitment to traps (Hartsuiker and Nicholson, 1981) should have equally affected catches by different mesh sizes in our study.

Captured fish size was approximately related to trap mesh size (Fig. 2), confirming earlier studies by Olsen et al. (1978), Stevenson and Stuart-Sharkey (1980), and Munro (1983). However, capture of a particular fish was not strictly a linear response to mesh size as measured by either the area of the mesh opening or the longest open dimension. Retention responses for a particular species were influenced by mesh shape as well as the size of the opening (Table 9).

Sutherland et al. (1987) showed that both fish size and body shape were important factors explaining differences in retention by a given mesh size between species. Slender (terete) fishes (e.g., eels, lizardfishes, cobia) of a given length (or weight) were much more likely to escape a partic-

ular mesh than were compressed fishes (e.g., angelfishes, triggerfishes, butterflyfishes) or depressed fishes (e.g., stingrays, flatfishes) of the same length. Rounded (fusiform) fishes fell between the two extremes. For example, a surgeonfish with a relatively slender body shape might escape a rectangular mesh but not a square mesh of the same area. A grouper which has a more rounded body shape might be more likely to escape a square mesh than a rectangular mesh. Thus, regulations of mesh size and shape aimed at optimizing one species may greatly affect capture of other species due to differences in body shape.

Total value, total species caught, number of individuals, and mean total weight per haul tended to decline with meshes larger and smaller than the 1.5″ hexagonal mesh (Fig. 4). Two of the minimum mesh sizes currently legally specified (1.5 × 1.5″, and 1.5″ hexagonal) had the greatest percentage contribution to total weight and total value. Mesh sizes 2 × 3″ and larger, especially, tended to catch larger fish but fewer species and individuals. Based on these results, the presently specified legal minimum mesh sizes appear to do little to reduce bycatch.

Catchability

Results show that catchability (the proportion of a population removed by one unit of fishing effort) can be greatly influenced by mesh size and shape. Fewer primary commercial species were caught with the largest mesh sizes. This reduced catch partially reflects the lower availability of large fish that can be retained in large meshes. Also, fish may be less willing to enter large meshed traps, perhaps because fewer retained fish make the trap less attractive.

Economics

Assuming constant effort, a larger mesh size would have immediate effects on total revenue of the trap fishery by lowering catchability. Larger mesh sizes would provide less revenue per trap haul. With larger mesh sizes, more effort (number of hauls) must be expended to obtain total revenue comparable with that of the smaller sized mesh. To achieve the same revenue with larger meshes as obtained with a 1.5″ hexagonal mesh, fishermen would have to increase their number of trap hauls anywhere from 1.5 to 13 times depending on the mesh size (Fig. 3, 4). The number of trap hauls fishermen can make is limited by their skill, manpower, time, and equipment.

The simple economic analysis done here is limited. It does not consider potential future benefits of allowing fish to escape and grow before entering the trap fishery, direct impacts on market prices due to supply, or possible losses to the future fishery from natural mortality. Also, price per pound is highly variable between markets and over time. These considerations are beyond the scope of this study.

Mesh Retention

Laboratory studies show that mesh retention depends on the species and size of the fish tested (Table 9) as well as on the mesh shape and size (Sutherland, et al., 1987; In press). These results do not consider availability in the fished area or willingness to enter traps. Laboratory tests of mesh retention on individual fish show only the physical limitation of fishes to escape a given mesh size. Quite possibly some fish passing though a given mesh in the laboratory would not, or could not, escape under actual field conditions. With these qualifications, Table 9 provides a basis to estimate mesh sizes necessary to allow the escape of fishes of specific sizes for the majority of commercial species. For example, mesh size of 2 × 3″ or larger should allow snapper and grouper less than 30.5 cm (12″) to escape.

Federal regulations in the Gulf of Mexico currently require four (2 × 2″) escape windows in each trap. The effects of escape windows were not specifically investigated in this study due to logistical, fiscal, and time limitations. However, a conservative approximation of their effect can be obtained by extrapolation of the data from 2 × 2″ meshes. In the extreme, the escape windows would make the trap function as 2 × 2″ meshed trap.

Based on our observations of fish behavior it is likely that most fishes able to escape a 2 × 2″ opening will freely swim in and out of the escape window while the trap is resting on the bottom. However, when a trap is pulled, most fishes react by swimming toward the bottom and are unlikely to find the escape window. Thus, injury and mortality from lifting and handling are still likely to occur. These fish would be more likely to escape during lifting if the entire top and bottom panels were made of the desired escape-sized mesh similar to the trap used in the field study.

An advantage of fish traps over bottom longline, trawl, or hook and line fishing is the increased selectivity of fish traps based on mesh size. It is possible to fish traps with meshes that reduce the capture of fish below a minimum size. Hooks are less selective for fish size; small fish can be captured on large hooks. Thus, the mortality and injury associated with lifting smaller fish off the bottom can be reduced or avoided with fish traps more easily than with hooks. Presumably undersized hooked fish still face trauma from handling and embolism even if released.

Summary

This study has described the effects of mesh size on selectivity, retention, catchability, and value of fish trap catches. Mesh size and shape influence trap retention. In this study the most effective mesh sizes for total revenue per haul and total weight were the 1.5 × 1.5″, and 1.5″ hexagonal meshes, two legally specified minimum mesh sizes.

Commercial species will enter a wide variety of mesh sizes. Increasing mesh size reduces catchability and revenue per haul which, within limits, can be compensated for by increasing effort (number of hauls). Adjusting mesh size offers a means for regulating and managing the reef fish fishery. Fish traps with appropriate mesh sizes potentially can reduce bycatch and undersized fish injury and mortality more effectively than similar manage-

ment measures applied to bottom longline, trawl, and hook and line fisheries.

Acknowledgments

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Cephalopod Resources of Venezuela

FREDDY AROCHA

ABSTRACT—The cephalopod resources of Venezuela are reviewed, based on previous literature and observations from commercial catches. The history of the squid and octopus fishery in the major fishing grounds is presented along with information on the catches and seasonality. Squids are landed in Venezuela throughout the year, with a high in February when most of the catch consists of the arrow squid, Doryteuthis plei. *Octopus,* Octopus vulgaris, *is abundant in the catches from June until October, with a peak in August-September. Methods of handling, processing, and marketing the cephalopod catch are discussed, and correctional guidelines are given. At present, the fishery is in disarray and there is an urgent need for study of Venezuela's commercial cephalopods.*

Introduction

The cephalopods in the Western Central Atlantic (FAO area 31) are an underdeveloped fishery resource. This is largely due to the present low commercial value of Venezuelan cephalopods on the world market and the low local appeal of cephalopods in the diet of Venezuelans.

In recent years however, the cephalopod landings have increased steadily throughout Area 31 (FAO, 1987).

According to FAO statistics for 1985 (FAO, 1987), the major cephalopod producing nations in the Western Central Atlantic are Mexico and Venezuela. While Venezuela has the lead in squid landings, consisting mainly of the arrow squid, *Doryteuthis plei*, Mexico leads the region in production of octopus (mainly *Octopus maya*). In Venezuela, both squid and octopus are produced as a by-catch of the shrimp fishery. Only Mexico has a directed fishery for octopus.

In the past 10 years, squid and octopus have become highly esteemed in the local Venezuelan markets, which in turn has lead to an increase in demand with corresponding economic consequences, i.e., cephalopods becoming, along with shrimp, a highly profitable product. Consequently, shrimpers have begun to look at cephalopods with a more commercial interest.

Few studies have been devoted to the knowledge of cephalopods in Venezuelan waters. There were some comments on octopus and squid production in the late 1960's (Voss, 1971, 1973) but without details on the species fished. Arocha and Urosa (1982) studied the seven octopus species common to the northeastern coast and commented on the fishery for *Octopus vulgaris*. Later, Arocha (1986) studied several aspects of the biology of *Doryteuthis plei*, *Loligo pealei*, and *Lolliguncula brevis* and the commercial cephalopod fishery in northeastern Venezuelan waters. Other studies relate to the culture and reproductive biology of noncommercial species, such as *Octopus briareus* and *Sepioteuthis sepioidea* (Robaina, 1983 and Robaina and Voglar, 1986). Most of our knowledge of Venezuelan cephalopods is restricted to the northeastern coast. However, there are unpublished data available[1] on the cephalopod resources from the rest of Venezuela. This study is an attempt to evaluate the state of the cephalopod resources in Venezuela and adjacent waters as an aid to the further development of the fishery. All observations were made by the writer, unless otherwise stated.

Table 1.—Commercial and potentially commercial cephalopods in Venezuelan waters.

Scientific name	English common name	Local common name
Neritic squids		
Doryteuthis plei	Arrow squid	Luria
Loligo pealei	Longfin squid	Luria
Loligo surinamensis	Surinam squid	Luria
Lolliguncula brevis	Brief squid	Chipiron
Sepioteuthis sepioidea	Caribbean reef squid	Chopo
Oceanic squids		
Illex coindetti	Southern shortfin squid	Pota
Ommastrephes pteropus	Orange-back squid	Calamar
Octopods		
Octopus vulgaris	Octopus	Pulpo

Resources of the Area

Twenty-two species of cephalopods are reported from Venezuela (Arocha and Urosa, 1982, 1985). Among these, five species are fished commercially (Table 1). Information on the commercially important species was given by Gines (1972, 1982), who reported on three of the five commercial species (*Doryteuthis plei*, *Loligo pealei*, and *Octopus vulgaris*) and summarized the available information on cephalopod landings from shrimp trawlers of two of the major fishing areas of Venezuela (Fig. 1), the Gulf of Venezuela and the northeastern coast from north of Tacarigua Lagoon to northeast of the Orinoco Delta. This latter region is divided into three subareas according to its landing ports. The main subarea is around Margarita

[1]The data used in this report are derived from various sources, although originating basically from the Direccion General de Desarrollo Pesquero del Ministerio de Agricultura y Cria of Venezuela. The original sources came from vessel logs, fish companies, and sales agents, and thus caution should be observed in its evaluation and use.

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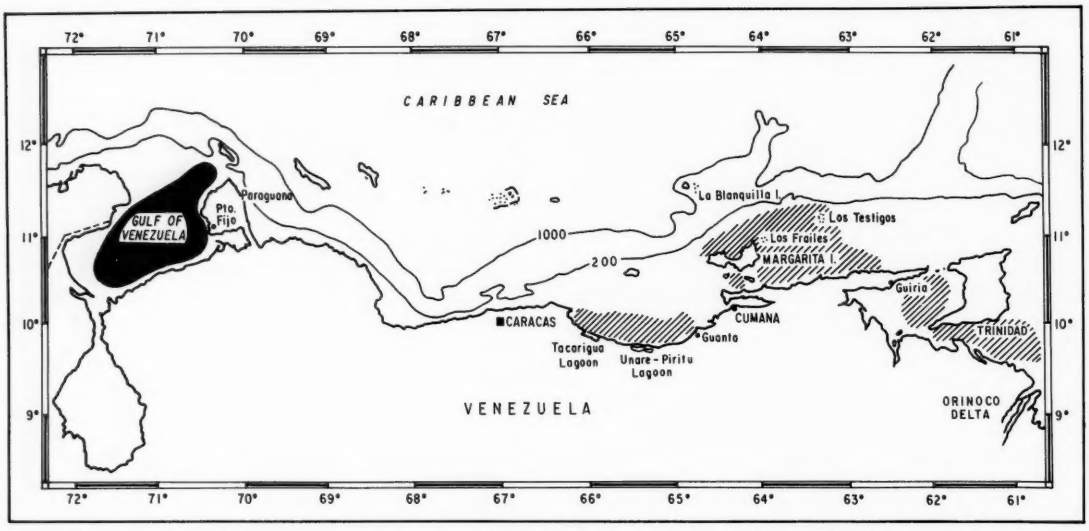

Figure 1.—Major fishing areas: The northwest area (NW) (black area) is in the Gulf of Venezuela and the northeast area (NE) (hatched area) is divided into three subareas: I, Unare-Piritu Lagoon; II, N, E, Margarita Island and III, N, NE of the Orinoco Delta. Depths in meters.

Island, followed by the subarea north of Unare-Piritu Lagoon and the subarea northeast of the Orinoco Delta, having as their landing ports Cumana, Guanta, and Güiria, respectively.

According to later knowledge, some of the geographical distributions presented by Gines (1972, 1982) are incomplete and inaccurate. It is now known from unpublished records and from interviews with fishing company officials, that *Doryteuthis plei* is the most abundant species in the squid landings from the Gulf of Venezuela and, to a lesser extent, *Loligo pealei* and *Lolliguncula brevis*. A similar situation is found in the northeastern coast, with the addition of *Loligo surinamensis* in the squid catches (Arocha, 1986).

The southern shortfin squid, *Illex coindetti*, the orange-back squid, *Ommastrephes pteropus*, and the rhomboid squid, *Thysanoteuthis rhombus*, are the only oceanic, oegopsid squids known from Venezuelan waters. There is little information on these species, except for *Ommastrephes pteropus* which is known to occur in large numbers along the northeastern coast off La Blanquilla Island, where it is fished at night from tuna "baitboats." *O. pteropus* is attracted to the surface by lights and caught with manually operated jigs. *Illex coindetti* is known from Venezuelan waters from only two specimens taken east of the Paraguaná Peninsula (Roper et al., 1969), although it is known from unpublished data that *I. coindetti* is common throughout the waters of the upper slope of the shelf (200 m) along the Venezuelan coasts. The lower Caribbean is thought to be the center of its geographical range in the Western Atlantic[2]. *Thysanoteuthis rhombus* is also known from only two specimens, one from the Gulf of Cariaco (Villa, 1973) and another fished east of Margarita Island (unpubl. data).

Octopus vulgaris is the only octopus fished commercially. However, small numbers of *O. burryi* and *O. zonatus* are mixed with the octopus landings from the northeastern coast, particularly from the area around Margarita Island. Although *O. macropus* had not been reported from Venezuelan waters, it is occasionally caught north of Los Frailes Island and landed mixed with *O. vulgaris*. The other species of octopus reported from Venezuela occur in small numbers, are of relatively small size, and have no commercial value.

Over 90 percent of the cephalopod catch of Venezuela is taken by double-rigged trawlers in the shrimp fleet. In 1987 the mean yearly catch of squid and octopus made by a trawler based at Cumana was 22.8 metric tons (t) and 10.8 t, respectively (source Venepesca). The standard commercial otter trawl used has a vertical opening of 3–4 m and a footrope of 29 m. The main body of the net has a stretched mesh of 5.2 cm with a stretched mesh of 4.2 cm in the codend. The trawl is fished at a constant speed of 2 knots. This method of squid fishing has its drawbacks because of the low speed at which the net is fished and the small opening of the net. Thus a substantial improvement in the squid catches could be made by increasing the trawling speed and the opening of the net. The rest of the cephalopod catch is taken by artisanal fishermen, mainly along the northeastern and, to a lesser

[2]Gilbert L. Voss. 1988. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Fla. Personal Commun.

extent, from the central coasts. The greater part of the artisanal squid catch (mostly *Doryteuthis plei*) is taken by hand jigging, while the octopus are caught in traps made of sections of used tires, called "longanizo."

Squid landings from the shrimp trawlers consist mainly of *Doryteuthis plei* from the Gulf of Venezuela, the central, and the northeastern coasts. East of the Orinoco Delta the main catch, although small, consists of *Lolliguncula brevis*, which occurs throughout the year and can withstand the low salinities of the area. *Doryteuthis plei* from the Delta area is only caught during the first half of the year when the salinity in the fishing area is 34–35‰. *D. plei* occurs from the southern United States southward to Brazil (Cohen, 1976; Roper et al., 1984). This tropical species is the largest loliginid in the area, and is near the center of its geographical distribution. It has a maximum mantle length of 370 mm northeast of Los Testigos Islands (Arocha, 1986). Most of the catches of this species are from depths of 20–55 m. It occurs throughout the year with a peak between February and April. *Loligo pealei* is a northern species, occuring from the Canadian Maritimes to the northern coasts of South America (Summers, 1983). The center of its range is in the middle Atlantic States (Voss and Brakoniecki, 1985). It attains a mantle length of up to 305 mm northeast of Los Testigos I. This species occurs in the Gulf of Venezuela and along the northeastern coast. This squid is taken from depths of more than 30 m from October to February when it is most abundant in the trawl catches. *Lolliguncula brevis* is widely distributed in the Western Atlantic, extending from Maryland to southern Brazil, but always associated with estuaries (Voss, 1973). In the southern Caribbean it attains a maximum size of 110 mm mantle length. It is a small species common throughout the year northeast of the Orinoco Delta. It is caught by shrimp trawlers in depths between 20–30 m. It also occurs in shallow waters around Margarita Island and in the Gulf of Venezuela. *Loligo surinamensis*, a species occuring in the southeastern Caribbean, is known only from northeastern Venezuela, particularly northeast of the Orinoco Delta and east of Margarita Island. It contributes a small part of the catch.

Octopus vulgaris is the largest species of octopus common to Venezuela. Little is known of the biology of this species in local waters. Studies on its ecology in Venezuela (Arocha and Urosa, 1982) show that it inhabits all types of bottoms: Sand, rock, mud, coral, and turtle grass (*Thalassia*) beds. It is nocturnal and feeds on mollusks and crustaceans. This species is caught from depths of 5–72 m, although high concentrations are reported from 24–38 m by the fishing companies. It is abundant from June until October with a peak in August–September when the animals come into shallow water to breed.

Cephalopod Production

Cephalopod landings in Venezuela are closely related to the history of the shrimp trawl fishery which originated in the Gulf of Venezuela in the early 1950's (Cadima et al., 1972). Squid were the only cephalopods reported in the landings from 1956 until the late 1960's and early 1970's, when the northeastern trawl fishery began to develop. From then on squid and octopus regularly appeared in the fishery statistics from the three major landing ports, Punto Fijo, Guanta, and Cumana.

Squid production in Venezuela can be roughly divided into four periods in terms of catch. Before 1969, squid catches were restricted to the Gulf of Venezuela where the shrimp fishery originated. From then on, part of the trawl fleet moved to new fishing grounds along the northeastern coast, mainly due to the depletion of the shrimp stocks in the Gulf of Venezuela in the late 1960's. An increase in the annual squid catch occurred, caused by the development of new fleets and discovery of new fishing grounds. The changes in the four periods can be outlined as follows (Fig. 2).

Period 1

The first period, from 1956 to 1969 (105–649 t, average 329 t), was when the trawl fishery was developing in the Gulf of Venezuela. During the 1950's, fishing was conducted by Italian stern-trawler-type vessels. Later, in the early 1960's, the fleet began to develop and new vessels arrived, mostly of the Florida shrimper type. During this period the production increased along with the fishing effort. From 1964 on, the fleet grew out of proportion to the fishery and, as a result, the fishing effort increased affecting almost all of the commercial stocks. The catch decreased even with an increased effort (Racca and Griffiths, 1972).

Period 2

The second period, from 1970 to 1978 (369–2,117 t, average 1,316 t),

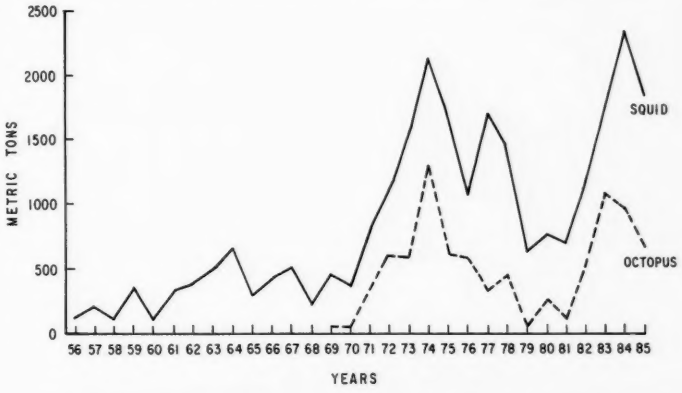

Figure 2.—Evolution of the annual cephalopod landings in Venezuela during 1956–85.

covers the expansion of the trawl fishery, with vessels operating in the three principal fishing grounds for shrimp and cephalopods: Gulf of Venezuela, north of Unare-Piritu Lagoon, and around Margarita Island. During this period an overall catch increase was reported. The decrease seen in 1976 is difficult to explain because of the lack of information on the fishery biology of the species involved, but was not due to a reduction of the fishing effort.

Period 3

The third period, from 1979 to 1981 (636–778 t, average 706 t), is distinctive for the abrupt decline in the catches. There are several possible explanations. One is the reduction of a considerable number of vessels in the three major fleets due to social and political factors and another is the heavy imports of cephalopods from Europe and the United States (California). The local fishing companies claim that this last factor was the main cause of the decline in the squid and octopus production due to an excess of cephalopods in the market and buyer preference for the imported squid.

Period 4

The fourth and last period, from 1982 to 1985 (1,171–2,370 t, average 1,794 t), is one of increase. Seafood imports were closed in late 1981 and the fleets again began to fish for squid. An important factor was the price increase combined with a steadily growing demand since 1982.

The squid production by areas and subareas is shown in Table 2. Of the two major areas, the Gulf of Venezuela and the northeastern coast, the highest squid production comes from the Gulf with a mean of 787.59 t during 1969–85 and 587.90 t for the whole period (1956–85). In the northeast, the mean catch reached 473.35 t, the subarea of Margarita Island accounting for 76.97 percent of the total catch with the subarea north of Unare-Piritu Lagoon accounting for the rest. In the northeastern area, squid are landed throughout the year with the highest frequency of catches in February and March and the lowest during the summer months (June–August). It is possible that a similar situation is present in the Gulf area where no monthly data are available.

The octopus production first appears in the statistics from about 1969 (Fig. 2), when the trawl fishery increased and fishing operations expanded to the present fishing grounds. It peaked in 1974 when 1,301 t were landed from the combined catches of the western and eastern fleets. After 1974 octopus production decreased steadily to its lowest level in 1979 and did not begin to recuperate until 1982. The low octopus production during the period between 1979 and 1981 was attributed to the same reasons of the low squid production during the period, competition with high imports. Another factor is that after 1974 octopus landings in the Gulf of Venezuela decreased to their lowest levels and they have hardly surpassed 100 t since (Table 3). There are no explanations for this decrease as there is a lack of biological information on the species.

Thus the northeastern fleet now produces the great majority of the octopus landings of Venezuela (85.6 percent). The major octopus production is from around Margarita Island with an average of over 300 t. The catch of the subarea north of Unare-Piritu Lagoon barely exceeds 95 t. In the northeastern area the octopus catch has a very marked seasonality. In the first 3–4 months of the year (January–April), octopus landings are almost nonexistant; they begin to appear in the statistics from late April on, with the highest peak in August–September. The landings drop to nearly zero by December. The primary octopus harvest in Venezuela is thus from late May till late October. Before and after this period the animals are small with no commercial value and appear in very low quantities.

Handling, Processing, and Marketing

On the vessels, squid and octopus are sorted from the haul and packed, regardless of size and overall condition of the specimens, in 12–14 kg plastic boxes with crushed ice on top. In port, octopus and squid are weighed and packed in 11 kg plastic bags with chilled water and repacked in plastic boxes. This method of handling squid and octopus produces a poor quality product, that cannot compete in the international markets. To improve the quality of squid and octopus some

Table 2.—Squid landings (t) from the major fishing areas and subareas[1] (1956–85).

	Areas and subareas				
	NW	NE			
Year		I	II	I+II	Total
1956	125				125
1957	221				221
1958	105				105
1959	345				345
1960	109				109
1961	320				320
1962	392				392
1963	503				503
1964	649				649
1965	303				303
1966	431				431
1967	521				521
1968	224				224
1969	361	10	84	84	455
1970	294	28	47	75	369
1971	508	157	115	272	780
1972	742	198	159	357	1,091
1973	1,286	115	231	346	1,532
1974	1,499	134	489	365	2,117
1975	747	370	578	948	1,695
1976	513	142	434	576	1,089
1977	917	243	551	794	1,711
1978	292	232	926	1,158	1,451
1979	190	66	380	446	636
1980	435	64	279	343	778
1981	372	37	294	331	703
1982	766	80	325	405	1,171
1983	1,205	82	492	574	1,779
1984	1,817	79	474	553	2,370
1985	1,445	74	336	410	1,855

[1]Subarea I = N of Unare-Piritu Lagoon and Subarea II = N, E of Margarita Island.

Table 3.—Octopus landings (t) from the major fishing areas and subareas[1] (1969–85).

	Areas and Subareas				
	NW	NE			
Year		I	II	I+II	Total
1969	0	4	60	64	64
1970	9	12	14	26	35
1971	17	226	93	319	336
1972	143	272	200	472	615
1973	297	88	213	301	598
1974	755	134	412	546	1,301
1975	40	122	460	582	622
1976	43	100	451	551	594
1977	105	76	156	232	337
1978	66	63	332	395	461
1979	5	4	55	59	64
1980	201	13	80	93	294
1981	13	3	111	114	127
1982	8	132	357	489	537
1983	43	115	934	1,049	1,092
1984	134	133	717	850	984
1985	135	51	486	537	672

[1]Subarea I = N of Unare-Piritu Lagoon and Subarea II = N, E of Margarita Island.

Table 4.—Ex-Vessel box price and total income in Venezuelan bolivares (Bs)[1] obtained from cephalopod revenues.

	Squid		Octopus	
Year	Bs/box	Million Bs	Bs/box	Million Bs
1978	110	15.96	120	5.53
1979	105	6.67	115	0.74
1980	85	5.40	140	4.11
1981	105	7.38	170	2.16
1982	105	12.29	165	8.86
1983	160	28.46	170	18.56
1984	225	53.32	230	22.63
1985	300	55.65	300	20.16
1986	400		400	
1987	700		700	

Cephalopod prices at different market levels in August 1985.

Item	Squid (Bs/k)	Octopus (Bs/k)
Ex-vessel	21.80	21.80
Distribuitor ("Cavero")	27.25	27.25
Wholesale	29.10 – 34.55	31.80 – 36.35
Retail	40.00 – 45.00	50.00 – 55.00

[1]From 1978–82, 1 US$ = 4.30 Bs; 1983, 1 US$ = 10.00 Bs; 1984–85, 1 US$ = 14.50 Bs; 1986–87, 1 US$ = 27.00 Bs (after 1983, the exchange rates are approximate).

quality control procedures must be introduced.

On the trawlers the squid and octopus should be packed in plastic boxes with crushed iced on top and bottom and with a plastic sheet between the ice and the product to avoid skin damage and deterioration. In the processing plant the squid and octopus should be graded in size and quality according to present international standards, packed, and frozen for marketing (Anonymous, 1982). Good quality control will bring better prices for a product that can compete in the export market. Squid and octopus are sold immediately upon arrival at the port, sometimes even before the ship docks. The buyer is a "Cavero" (middleman or dealer) who takes the product to the main wholesale fish market in Caracas or sells it directly to restaurants. In the main wholesale fish market, the cephalopods are sold to other local wholesale and retail markets or transported to markets throughout the nation.

All of the squid and octopus landed by the shrimp fleet is sold in the domestic market where there is a steadily rising demand that maintains the price at a competitive level (Table 4). There is little interest from the producer's point of view in exporting the product because of the domestic demand which does not require grading and classifying the product or quality control. On the other hand, the way the local product is handled is the reason why consumers preferred high quality imported cephalopods over the local product. It was the decrease in the demand for the local squid and octopus that caused the decline in the landings during 1979–81. The local fishery was rescued by excluding cephalopod imports, and if cephalopods imports are again permitted, the local fishery will survive only if proper handling, grading, and quality control is required.

Conclusions

This report shows that little is known about the biology of the squid and octopus species fished in Venezuela, despite the great local demand for them. Likewise, there is little information on stock sizes, populations, population dynamics, species distributions and spawning grounds of the commercially important species. There is an urgent need for such studies if this growing fishery is to be maintained and properly managed. A program to gather and analyze catch statistics would be a first step. At present the fishery is in disarray, and without proper management while still in its infancy it could suffer disastrous changes in the coming years.

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U.S. Seafood Exports in 1988 Set Record; Fish Consumption Down

The United States exported $2.2 billion worth of seafood in 1988, making it the best year ever, and beating the 1987 record export figure by 37 percent, the National Oceanic and Atmospheric Administration (NOAA) announced in March. U.S. seafood imports, always higher than exports, fell for the first time in 14 years, as Americans bought $5.3 billion worth of edible fishery products from abroad, 5 percent below the 1987 total. Most of these purchases were high-value products like cod, shrimp, tuna, and lobster.

The bulk of the U.S. exports went to Japan, traditionally the United States' best customer. In 1988 Japan purchased almost $1.6 billion worth of seafood, up 49 percent from 1987. Seventy-three percent of the value of all U.S. seafood exports went to Japan last year, NOAA said.

"The strong yen, Japan's high per capita income, and its vigorous economy have combined to make it our biggest market," said Terry Ellington, an economist with NOAA's National Marine Fisheries Service. In addition, Ellington said, Japan's access to other countries' fishing zones has been drastically curtailed recently. In the early 1980's, for example, Japan was harvesting well over a million tons of fish each year from U.S. waters. Last year its fishing allocation in the U.S. zone was reduced to zero.

Canada was the United States' second biggest seafood buyer, with $156 million in purchases, down 1 percent from 1987. Following were the United Kingdom ($80.5 million), France ($71.7 million), and South Korea ($43.8 million). Only the United Kingdom showed any appreciable change—up 17 percent—from the 1987 figures. Salmon, in one form or another, made up the bulk of American fish sold abroad, accounting for 44 percent of the total value of U.S.-exported seafood.

Fish Product Exports

In 1988, Pacific Northwest and Alaska exports of edible fishery products scored an impressive 31 percent increase in quantity from 1987 to 795.7 million pounds or 360,944 metric tons (t); the value of these fishery exports increased by 38 percent to $1.7 billion. Northwest and Alaska exports comprised 78.6 percent of total U.S. edible fishery exports, up slightly from 78.1 percent in 1987. A substantial rise in exports of whole or dressed salmon, other finfish, and snow crab contributed to the increase. In 1988, Pacific Northwest and Alaska exports were shipped to 33 countries. The top six countries accounted for over 96 percent of the total.

Increased trade with Japan accounted for most of the gain, as exports to Japan totaled $1.4 billion or 82 percent of the total, up from $936.7 million and 76 percent in 1987. Canada was a distant second with $90.4 million or 5.3 percent of the total, down from $92.5 million and 7.5 percent in 1987. Pacific Northwest and Alaska exports to the United Kingdom and the Republic of Korea registered increases to $66 million or 3.9 percent, and $35.9 million or 2.1 percent, respectively. Exports to France fell drastically, with lower sales of whole or dressed salmon contributing to the decrease.

Over-the-side deliveries by U.S. fishing vessels to foreign processing vessels, commonly called joint ventures sales, off the Pacific Coast amounted to 3.15 billion pounds or 1.43 million t, with an estimated value of $220 million. These sales are not included in U.S. trade statistics; if they were included, Pacific Northwest and Alaska exports of edible fishery products would equal $1.9 billion and comprise 80 percent of U.S. fishery exports.

Kodiak, Alaska, Sets Fish Landings Record

Fish landed at Kodiak, Alaska, in 1988 were worth more than $166 million, establishing a new record for the value of landings in the United States and making it the nation's number one port, a position it has not held since 1981, the National Oceanic and Atmospheric Administration (NOAA) has announced. The Massachusetts port of New Bedford was second, with fish landings valued at $141 million, NOAA said. In 1987 Kodiak's fish landings were worth $144 million.

Cameron, La., was first in volume in 1988, with 439 million pounds of fish landed, mostly low-value menhaden, used for livestock feed and industrial oil. Cameron has been the largest volume U.S. port for more than a decade, but last year's landings were the lowest since 1977. In 1987, 672 million pounds of fish were landed at Cameron.

Several other Alaska ports experienced large increases in either the value or volume of their landings in 1988. Landings at the twin port of Dutch Harbor-Unalaska went from 128 million pounds in 1987 to 377 million pounds last year. Ketchikan's landings virtually doubled in value from $23 million in 1987 to $44 million in 1988. And leading-port Kodiak's landings rose from 204 million pounds in 1987 to 305 million pounds last year. In all, six Alaskan ports were among the ten top money makers last year, and two were among the top ten volume ports. The ten leading U.S. ports in volume of fish and shellfish landed in 1988 (in millions of pounds), with 1987 figures for comparison:

Table 1.—Preliminary landings and values of fish and shellfish in New England on a state-by-state basis in 1987 and 1988.

State	1987		1988	
	Million pounds	Million dollars	Million pounds	Million dollars
Mass.	258.1	278.9	286.5	274.0
Maine	170.1	132.4	155.9	123.6
R.I.	100.2	77.4	106.3	69.4
N.H.	8.3	7.7	10.8	8.8
Conn.	8.6	16.0	9.1	17.4
Total	545.2	512.4	568.6	493.2

Note: Landings of fish, lobster, and crab in live weight; landings of other shellfish in meat weight.

Table 2.—Preliminary landings and values of fish and shellfish in New England on a port-by-port basis in 1987 and 1988.

Port	1987		1988	
	Million pounds	Million dollars	Million pounds	Million dollars
Gloucester, MA	93.0	34.0	107.4	30.8
New Bedford, MA	78.7	143.7	90.3	141.0
Pt. Judith, RI	46.6	27.4	49.7	25.5
Portland, ME	43.8	35.8	43.9	30.4
Rockland, ME	38.7	8.1	40.6	6.7
Provincetown/ Chatham, MA	25.3	12.7	25.2	11.1
Boston, MA	23.0	16.9	20.8	14.5
Newport, RI	11.8	12.4	12.8	11.6

Note: Landings of fish, lobster, and crab in live weight; landings of other shellfish in meat weight.

Table 3.—Preliminary landings and values of fish and shellfish in New England on a species-by-species basis in 1987 and 1988.

Species	1987		1988	
	Million pounds	Million dollars	Million pounds	Million dollars
Atlantic herring	84.5	4.4	89.1	5.1
Atlantic cod	58.4	43.7	75.4	42.3
Northern lobster	42.8	124.7	45.2	133.6
Pollock	44.6	17.8	32.9	11.1
Silver hake	25.9	7.3	24.9	5.3
Sea scallop	18.2	80.6	18.4	80.0
Win. flounder	18.4	22.7	16.7	20.7
Yel. flounder	16.4	18.7	10.9	13.0
White hake	11.7	5.2	10.5	3.2
Scup	7.8	5.1	7.9	5.4
Sum. flounder	8.7	14.3	7.7	11.6
N. shrimp	11.1	12.2	6.8	7.5
Haddock	6.6	8.5	6.4	7.0
Swordfish	2.5	8.6	4.1	12.0

Note: Landings of fish, lobster, and shrimp in live weight; landings of scallops in meat weight.

Port	1987	1988
Cameron, La.	672.4	438.9
Dutch Harbor-Unalaska, Alaska	128.2	377.3
Kodiak, Alaska	204.1	304.6
Empire-Venice, La.	357.4	297.2
Pascagoula-Moss Point, Miss.	391.6	292.0
Dulac-Chauvin, La.	331.7	244.1
Los Angeles, Calif.	203.1	232.0
Intercoastal City, La.	314.3	209.7
Beaufort-Morehead City, N.C.	85.7	110.0
Gloucester, Mass.	93.0	107.4

The ten leading U.S. ports in value of fish and shellfish landed in 1988 (in millions of dollars), with 1987 figures for comparison:

Port	1987	1988
Kodiak, Alaska	132.1	166.3
New Bedford, Mass.	143.7	140.9
Dutch Harbor-Unalaska, Alaska	62.7	100.9
Kenai, Alaska	n/a	99.3
Empire-Venice, La.	60.1	67.7
Petersburg, Alaska	36.9	58.5
Dulac-Chauvin, La.	65.6	56.5
Cordova, Alaska	41.9	46.4
Aransas Pass-Rockport, Tex.	36.4	45.6
Ketchikan, Alaska	22.8	43.5

New England Harvest Up in Weight

Preliminary figures for commercial landings of New England fish and shellfish during 1988 were 568.6 million pounds, valued at $493.2 million. These 1988 figures are up 23.4 million pounds, but down $19.2 million, from the 1987 figures, according to Allen E. Peterson, Jr., Science and Research Director of the National Marine Fisheries Service's Northeast Region.

This marks the first time since 1984 that the value of New England landings has failed to increase. In the past, decreases in the value of New England landings have generally been attributed to increases in the imports of less expensive Canadian fishery products. However, imports of cod and other finfish from Canada to New England dropped from 1.08 billion pounds in 1987 to 0.95 billion pounds in 1988, indicating that there are probably other market factors affecting prices. Tables 1-3 compare the landings and values of New England fish and shellfish in 1987 and 1988 on a state, port, and species basis. Table 4 has also been included on landings and values of lobsters in each of the New England states.

Table 4.—Preliminary landings and values of lobster in New England on a state-by-state basis in 1987 and 1988.

State	1987		1988	
	Million pounds	Million dollars	Million pounds	Million dollars
Maine	19.8	54.6	21.7	60.7
Mass.	15.0	43.8	15.5	47.3
R.I.	5.3	17.8	4.9	15.6
Conn.	1.6	5.3	2.0	6.8
N.H.	1.1	3.2	1.1	3.2
Total	42.8	124.7	45.2	133.6

Note: Landings in live weight.

Fish Consumption Down

The U.S. per capita consumption of commercially produced seafood fell to 15.0 pounds in 1988, following 5 straight years of increases, the National Oceanic and Atmospheric Administration (NOAA) reports. The drop, from a record 15.4 pounds per person in 1987, was not unexpected, according to NOAA's National Marine Fisheries Service. Fisheries Service marketing experts said record-breaking seafood exports in 1988, combined with lowered imports, especially frozen blocks of fish steaks and fillets, reduced the overall amount of fish available in the United States.

Consumption of fresh and frozen fish fell from a record 10 pounds per person in 1987 to 9.6 pounds last year. Both canned and cured seafood held steady during the same period at 5.1 and 0.3 pounds per person respectively. The per capita consumption of shrimp rose to a record 2.4 pounds in 1988. The previous record was 2.3 pounds, in 1987. The per capita figures represent the consumption of

edible meat rather than the weight of the whole fish or shellfish, NOAA said.

"Red Tide" Caused 1987 Dolphin Deaths

Hundreds of bottlenose dolphins that died off the east coast of the United States during the summer of 1987 and into early 1988 were poisoned by eating fish tainted by a naturally occurring toxin from "red tide" algae, according to the National Oceanic and Atmospheric Administration (NOAA). The red tide alga, known as *Ptychodiscus brevis*, produces the powerful poison, brevetoxin, which killed some of the dolphins directly, NOAA said, and weakened others making them more susceptible to a host of bacterial and viral infections. NOAA reported that this is the first known instance of the toxin's being transmitted to a mammal through tainted fish.

The toxin itself was confined to the liver and other viscera of the fish. It is not present in the flesh and poses no threat to humans eating fish fillets, NOAA said. The toxin was carried up the coast by fish—possibly menhaden or Spanish mackerel that had eaten menhaden—which had consumed the algae. Red tides are normally confined to the Gulf of Mexico, although occasionally such algal blooms can be carried around Florida and swept north along the Atlantic coast by the Gulf Stream.

Dead dolphins first began washing ashore in southern New Jersey in late June 1987. In early August, NOAA and the U.S. Marine Mammal Commission assembled an investigative team in Virginia Beach, Va., to examine stranded dolphins, collect tissue samples, and begin an analysis that would eventually involve almost 350 dolphins in thousands of separate tests. The team was headed by Joseph Geraci, a veterinarian working at the University of Guelph in Ontario, and at one point involved more than 100 volunteer scientists and others at dozens of Federal, university, and private agencies and laboratories. The brevetoxin analyses were carried out in the laboratories of Dan Baden at the University of Miami. By March of 1988, when the event ended, about 740 dolphins had washed ashore from New Jersey to Florida. NOAA estimates a substantially larger number died and were lost at sea.

Argentine-Soviet Fishery Relations Reviewed, 1966-88

Argentina and the Soviet Union have had a long, but volatile history of fishery relations, which have ranged from close commercial exchanges to tragic confrontations at sea. The Soviets have long been interested in the rich—and underexploited—fishing grounds on Argentina's Patagonian shelf. The Argentines, however, have been very protective of their fishery resources, and successive Governments hesitated to permit foreign fishing. Even so, after being expelled from Argentine waters in 1967, the Soviets repeatedly tried to negotiate an access agreement.

Initially inconsequential cooperation agreements, signed in the 1970's, were finally supplanted by the conclusion of an actual access agreement in 1986. Argentina is currently the only Latin American country permitting significant Soviet fishing within its 200-mile limit, although unconfirmed reports suggest that the Soviets signed an access accord with Peru in early December 1988. Under the terms of the Argentine agreement, the Soviets are permitted to catch up to 180,000 metric tons (t) of fish in Argentine waters annually. Although the agreement has been widely criticized in Argentina, the Argentine Government announced on 30 October 1988, that the agreement would be renewed for a third year.

Soviet Distant-water Fishing Overview

The Soviet Union was the world's second most important fishing country in 1987 (behind only Japan), recording a catch of almost 11.2 million metric tons. About 30 percent of the Soviet 1987 catch was taken in distant-water fisheries (Tables 1, 2). The distant-water catch has declined in recent years. Distant-water fishing represented more than 40 percent of the total Soviet catch during the early 1970's, but then declined due to the proliferation of 200-mile claims in 1976 and 1977. The Soviet catch in 1978 was only 8.9 million t, more than a 10 percent decline from the 10.1 million t taken in 1976. The Soviets partially compensated for the loss of access to distant-water grounds off other countries by intensifying fishing effort in their own coastal areas. Coastal catches increased to a record 7.2 million t by 1984, but have since declined. Most of this expansion was focused along the Soviet Union's Pacific coast because the Soviets and various European countries were already heavily fishing stocks in the North and Barents Seas.

The importance of the distant-water catch to the Soviet fishing industry required Soviet fishery officials to develop new fisheries and negotiate access agreements to avoid long-term catch declines. As a result of these efforts, by 1984 the Soviet fishing fleet was breaking its catch records set prior to the proliferation of 200-mile regimes. The Soviets were unable to retain access to North American grounds because of strict U.S. and Canadian enforcement efforts. This setback, however, was partially offset by sharply higher catches off Latin America and Antarctica (Fig. 1). The Soviets conduct active international fishery relations and, next to the Japanese, have the most complex network of bilateral fishery relations. Their access and joint venture agreements have been primarily with developing countries, especially African countries.

African Grounds

After being expelled from Argentine grounds in 1967, the Soviets began to

Table 1.—The Soviet fish catch by area[1], 1965-86.

Year	Catch (1,000 t)							
	L. America	N. America	Africa	Antarctic	Oceania	Inland	Coastal	Total
1965	17.3	1,362.6	479.2			826.4	2,414.4	5,099.9
1966	110.7	1,385.9	516.2			789.0	2,547.0	5,348.8
1967	701.6	1,192.2	442.7			816.0	2,624.7	5,777.2
1968	249.4	1,228.3	813.4			780.5	3,010.5	6,082.1
1969	122.8	1,625.5	997.7			746.5	3,005.9	6,498.4
1970	440.8	1,559.1	1,082.1			853.4	3,316.8	7,252.2
1971	39.3[2]	1,677.7	1,468.2		13.0	935.4	3,203.4	7,337.0
1972	126.4[2]	2,019.2	1,697.6		53.7	870.0	2,990.0	7,756.9
1973	192.3[2]	1,737.2	1,635.0		74.8	849.6	4,129.9	8,618.8
1974	60.7	1,854.7	1,727.6		89.5	772.9	4,737.5	9,242.9
1975	108.3	1,739.5	1,564.2		44.8	944.0	5,475.1	9,875.1
1976	33.5	1,349.3	2,178.6	57.6	78.0	770.3	5,664.6	10,132.2
1977	27.9	617.8	2,254.2	362.9	129.0	770.8	5,187.9	9,350.7
1978	54.0	456.5	2,291.3	298.3	72.8	730.4	5,011.4	8,914.8
1979	548.9	355.5	1,388.5	439.2	71.6	805.6	5,516.8	9,114.0
1980	580.1	167.5	1,804.3	526.7	73.6	747.0	5,576.5	9,475.8
1981	624.3	116.6	1,713.8	515.9	66.8	806.9	5,701.7	9,545.9
1962	627.2	112.5	1,869.2	601.7	76.8	803.6	5,865.7	9,956.7
1983	682.5	87.5	1,598.1	375.6	100.1	856.4	6,116.4	9,816.7
1984	663.3	151.6	1,401.5	196.5	72.8	881.5	7,225.5	10,592.9
1985	696.5	144.4	1,437.9	216.3	75.9	905.6	7,046.1	10,522.8
1986	790.7	156.7	1,575.8	431.2	165.2	926.9	7,213.5	11,260.0
1987	1,013.5	163.5	1,779.9	384.2	166.6	988.4	6,663.6	11,159.6

[1]Latin America includes FAO areas 31, 41, 77, and 87. The area described as North America includes FAO Areas 21 and 67. The area described as Africa includes FAO Areas 34, 47, and 51, and Oceania includes FAO Areas 57, 71, and 81. Soviet coastal zones are FAO Areas 18, 37, and 61.
[2]Does not include catch of Soviet vessels leased by Chile, 1970-73.

fish African grounds intensively. African countries, as a result, responded by extending their own coastal zones in the late-1970's. The Soviets successfully negotiated bilateral fishing agreements with many of those governments, but several of those countries have been dissatisfied with the results achieved. African officials had hoped that the Soviets would help develop their local fisheries. Results in terms of increased catch and expanded export earnings have been limited.

Some African officials are convinced that the Soviets have significantly under reported their catch and are concerned about the impact of this intense fishing effort on stocks. Few African countries have the enforcement capability to closely monitor distant-water operations. Some African countries have terminated their agreements with the Soviets. Other countries have attempted to develop fishery relations with noncommunist countries. A variety of access and joint venture agreements have been negotiated with the European Community, Japan, South Korea (ROK), and other countries. Despite the Soviets' difficulties with African countries, African waters remain the Soviets' most important distant-water fishery, even accepting Soviet catch statistics.

Table 2.—The Soviet fish catch by area[1] and regional importance by percentage, 1965-86.

Year	Catch (percent)							
	L. America	N. America	Africa	Antarctic	Oceania	Inland	Coastal	Total
1965	0.3	26.7	9.4			16.2	47.3	100.0
1966	2.0	25.9	9.7			14.6	47.6	100.0
1967	12.1	20.6	7.7			14.1	45.4	100.0
1968	4.1	20.2	13.4			12.8	49.5	100.0
1969	1.9	25.0	15.4			11.5	46.2	100.0
1970	6.1	21.5	14.9			11.8	45.7	100.0
1971	0.5[2]	22.9	20.0		0.2	12.7	43.7	100.0
1972	1.6[2]	26.0	21.9		0.7	11.2	38.5	100.0
1973	2.2[2]	20.2	19.0		0.9	9.9	47.9	100.0
1974	0.7	20.1	18.7		1.0	8.5	51.3	100.0
1975	1.1	17.6	15.8		0.5	9.6	55.4	100.0
1976	0.3	13.3	21.5	0.6	0.8	7.6	55.9	100.0
1977	0.3	6.6	24.1	3.9	1.4	8.2	55.9	100.0
1978	0.6	5.1	25.7	3.3	0.8	8.2	56.2	100.0
1979	6.0	3.7	15.2	4.8	0.8	8.8	60.5	100.0
1980	6.1	1.8	19.0	5.6	0.8	7.9	58.8	100.0
1981	6.5	1.2	18.0	5.4	0.7	8.5	59.7	100.0
1982	6.3	1.1	18.8	6.0	0.8	8.1	58.9	100.0
1983	7.0	0.9	16.3	3.8	1.0	8.7	62.3	100.0
1984	6.3	1.4	13.2	1.9	0.7	8.3	68.2	100.0
1985	6.6	1.4	13.7	0.2	0.7	8.6	67.0	100.0
1986	7.0	1.4	14.0	3.8	1.5	8.2	64.0	100.0
1987	9.1	1.5	15.9	3.4	1.5	8.9	59.7	100.0

[1]Latin America includes FAO areas 31, 41, 77, and 87, and the area described as North America includes FAO Areas 21 and 67. The area described as Africa includes FAO Areas 34, 47, and 51, and Oceania includes FAO Areas 57, 71, and 81. Soviet coastal zones are FAO Areas 18, 37, and 61.
[2]Does not include catch of Soviet vessels leased by Chile, 1970-73.

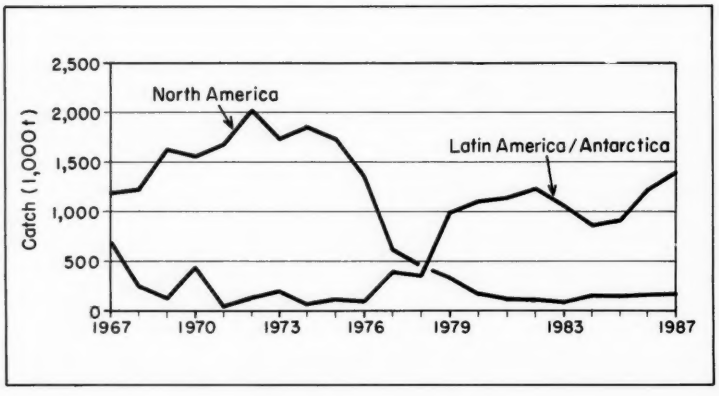

Figure 1.—Soviet Union distant-water fish catch fluctuations, 1967-87.

Latin American Grounds

Soviet catches off Latin America have fluctuated significantly since the Soviets first began to research potential grounds (1961) and commenced a commercial fishery (1965) (Table 1, 2). Soviet fishing operations off Latin America were complicated by the lack of diplomatic and commercial ties with Latin countries. The Soviets developed close fishery relations with Cuba after the 1959 revolution, but found Caribbean stocks ill-suited for their large stern factory trawlers. In recent years, Latin America's relative importance as a distant-water fishery for the Soviet fleet has increased steadily, especially after Soviet fishing on North American grounds was sharply restricted in 1977 (Table 1, 2). The Soviets caught a record 1.0 million t of fish off Latin America in 1987, more than a 20 percent increase over the previous record catch (0.8 million t, reported in 1986). About 30 percent of the entire Soviet distant-water catch was taken off Latin America in 1987 (Fig. 2). The Soviets primarily operate on two grounds in Latin America: The Eastern Pacific (off Peru and Chile), and the Southwest Atlantic (off Argentina).

Eastern Pacific

The primary Soviet fishing ground in Latin America since 1979 has been the Eastern Pacific off Peru and Chile. About 85 percent of the Soviet 1987

Table 3.—The Soviet fish catch off Latin America, 1965-86.

Year	FAO area[1] catch (1,000 t) 31[2]	41	77[2]	87[3]	Total
1965	17.3				17.3
1966	37.4	73.3			110.7
1967	23.9	677.7			701.6
1968	6.8	189.8	52.8		249.4
1969	4.8	92.6	25.4		122.8
1970		420.6	20.2		440.8
1971	11.2	26.2	1.9		39.3
1972	73.8	4.6	12.9	35.1	126.4
1973	8.9	6.1	138.1	39.2	192.3
1974	25.6	12.9	22.2		60.7
1975	69.0	8.7	30.6		108.3
1976	23.8	9.7			33.5
1977		27.9			27.9
1978			Negl	54.0	54.0
1979		2.2	0.1	546.6	548.9
1980		27.7		552.4	580.1
1981		17.2	2.2	604.9	624.3
1982		19.0	0.2	608.0	627.2
1983		66.1	1.4	615.0	682.5
1984		58.0	0.2	605.1	663.3
1985		70.9	1.1	624.5	696.5
1986		77.1	2.7	710.9	790.7
1987		168.5	0.1	844.9	1,013.5

[1]FAO Area 31 = Western Central Atlantic, 41 = Southwestern Atlantic, 77 = Eastern Central Pacific, and 87 = Southeastern Pacific. The Soviets also fish in Antarctic waters claimed by Argentina and Chile (FAO areas 48 and 88). As the United States does not recognize the Argentine and Chilean claims, the Soviet fisheries catch there is not included in the above Latin American totals. The main Soviet fishery in the Antarctic is for krill.
[2]May include small amounts taken off the United States.
[3]Does not include catch of Soviet vessels leased by Chile.

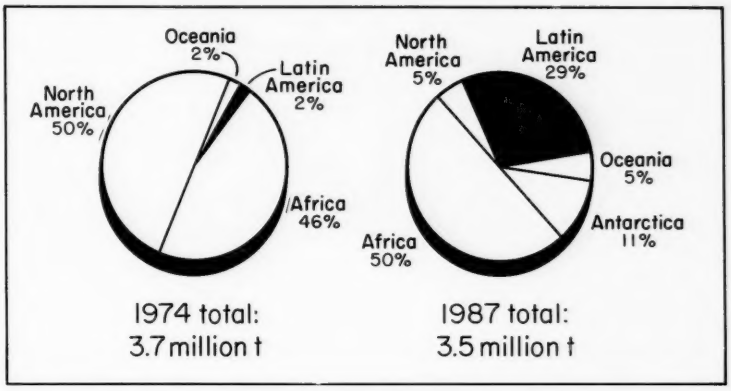

Figure 2.—Soviet distant-water fish catch by region, 1974 and 1987.

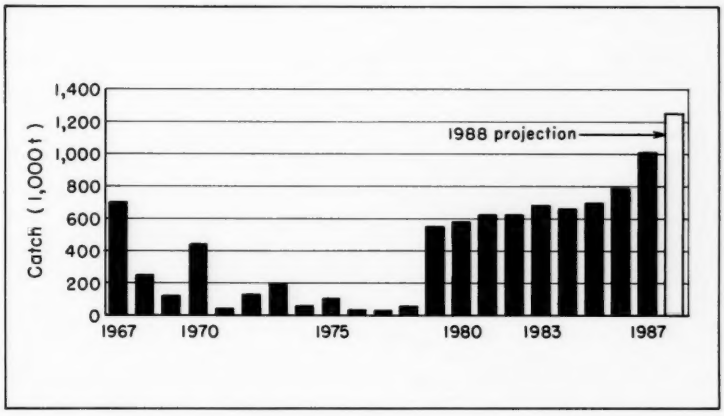

Figure 3.—Soviet fish catch off Latin America, 1967-68.

catch off Latin America was taken in the Eastern Pacific, outside the 200-mile zones of Peru and Chile (Fig. 3, Table 3). The Soviets have generally been excluded from Peruvian and Chilean waters, but have heavily fished the Eastern Pacific outside their 200-mile zones. Chilean relations were close with the Allende Government. The Soviets leased five stern factory trawlers to a Chilean state-owned fishing company in 1972-73, but have had no diplomatic or commercial relations whatsoever with Chile since the overthrow of President Allende in 1973. Peruvian relations have been much more fruitful. The Soviets have had a fisheries cooperation agreement with Peru since 1973 (which includes landing rights to exchange crews and service vessels in Peruvian ports). Two short-lived and unpopular Soviet-Peruvian joint ventures permitted the Soviets to catch small quantities of fish in Peruvian waters in 1985 and 1986, but the Soviets have generally been prohibited from fishing within Peru's 200-mile zone. The Soviets are, however, currently trying to finalize a major new agreement that would permit them to catch up to 400,000 t of fish in Peruvian waters annually.

Southwest Atlantic

The Southwest Atlantic has been a secondary ground for the Soviets, except for a brief period (1966-70) before Argentina and Brazil moved to establish 200-mile zones. The Soviets have continued to seek access to both Argentine and Brazilian coastal waters. Even after signing an access agreement with Argentina, however, the total Soviet catch in the Southwestern Atlantic was only about 15 percent of their entire Latin American catch in 1987. Even so, the Southwest Atlantic has some advantages over the Eastern Pacific. First, the Soviets have access to demersal stocks in the South-

west Atlantic, while their catches are mostly less desirable pelagic species in the Eastern Pacific. Second, the Soviets can coordinate their Southwestern Atlantic fishery with similar operations off Southern Africa in the Southeast Atlantic.

Soviet South Atlantic Fishery

Patagonian Shelf Activity, 1961-67

The Soviets first deployed vessels off Argentina in 1961. The first vessels were research vessels which began to access stocks on the virtually untouched Patagonian shelf. Soviet exploratory research work continued there for several years. Soviet fishing vessels (using the research data that had been accumulated) initiated commercial operations with considerable success in early 1966, catching 73,300 t of fish (Table 3). Most of that catch was hake (56,000 t). Soviet South Atlantic operations were made possible by the build-up in the mid-1960's of the Soviet fleet of motherships which could deliver supplies and pick up the catch of the factory trawlers at sea, permitting the Soviets to operate on distant grounds without local support bases.

200-Mile Declaration

The Argentine Government responded swiftly to the massive new Soviet fishery in 1966. Argentine officials were astounded by the scale of the Soviet effort. The initial Soviet catch results were impressive, totaling over 73,000 t. Thus, in just 1 year the Soviets managed to achieve a catch nearly one-third of Argentina's entire catch of about 250,000 t. The Argentine Government was particularly concerned as most of the Soviet catch was hake, the primary species utilized by Argentine fishermen. In addition, the Soviets were planning a massive expansion of the fishery in 1967. After the dimensions of the Soviet effort had become apparent, the Government of General Juan Carlos Onganía declared a 200-mile Territorial Sea on 4 January 1967 (Decree No. 17094). Most countries at the time claimed only 12-mile coastal zones, but the Argentines were following the example set by Peru (1947), Costa Rica (1948), Ecuador (1951), and Chile (1953) which had already declared varying forms of 200-mile coastal zones. The Argentine Foreign Ministry stated that the action was necessary because of extensive foreign fishing activities, "specifically of communist nations." Especially troublesome to the Argentine military regime were allegations that Soviet and Cuban fishing vessels were smuggling arms and advisers to subversive groups in Argentina. In addition, local fishermen complained that the Soviets operated unusually close to Argentina's coast. Before the announcement of the 200-mile claim, some fishermen even reported seeing Soviet fishing vessels within Argentina's 3-mile Territorial Sea. Other Argentine fishermen claimed that the Soviets were using illegal fishing methods such as "blasting" (*Washington Daily News*, 12 December 1966) (the use of explosives to kill or stun large quantities of fish), but there is no evidence to support these allegations. Not all Argentines favored the implementation of the new 200-mile zone. Some critics of the military regime alleged that Soviet fishing activities were being overstated to give the Argentine Navy an excuse to enlarge the fleet, as additional vessels would be needed to patrol the expanded zone.

Initial Fishing Regulations

Shortly after the 200-mile declaration, the Argentine Government issued regulations enabling foreign fishermen to buy fishing licenses to operate in Argentina's 200-mile zone. Interested foreign fishermen had to pay a nominal fee (about $30 per vessel, renewable every 2 months) for fishing rights. (The Argentines had apparently decided that, initially, establishing the principle of Argentine jurisdiction was more important than generating revenue). The Argentine Navy began to enforce the new licensing regime on 29 January 1967, and issued warnings to several Soviet fishing captains, who then paid the fees. (Soviet officials claimed that the fees were paid by the vessel operators—not the Soviet Government. They made this distinction—ignoring the fact that all Soviet fishing vessels are owned and operated by an agency of the Soviet Government—to avoid an official recognition of Argentine jurisdiction.)

The Soviet Embassy in Buenos Aires released a statement on 2 February 1967, disputing the right of any country to claim a 200-mile Territorial Sea, and calling on the Argentine Government to reverse its decision. Despite their diplomatic objections, the Soviets continued to purchase the Argentine fishing licenses. As a result of their successful experience in 1966, the Soviets sharply increased the number of vessels deployed in the Southwest Atlantic during 1967. In late 1967, about 70 large Soviet stern factory trawlers (including seven motherships) operated in Argentine waters under the Argentine licensing regime.

New Regulations Prompted

The Argentine Government, by September 1967, had become greatly concerned about the massive foreign fishing effort conducted under its licensing regime. Soviet trawlers caught a record 677,700 t of fish in Argentine waters during 1967, almost three times the Argentine catch of 241,000 t. (The other countries fishing off Argentina caught significantly less fish in 1967. Japan caught 4,400 t, West Germany caught 2,000 t, and Cuba caught 1,600 t.) As a result, Argentina issued new foreign fishing regulations in October 1967 which were originally to be implemented on 24 December of that year. The new law increased the licensing fees, required foreign fishermen to report their catches to the Argentine Government, and placed quantitative limits on the catches. The implementation of the law was delayed until 1 April 1968, and in the interim the governments of Brazil, Germany (FRG), Japan, Spain, and the U.S.S.R. tried to negotiate more favorable terms for their fishermen. Negotiations between the Soviets and Argentines broke down in early 1968, however, because the Soviets refused to either report their catches or

Table 4.—Bilateral fishery agreements between Argentina and the Soviet Union, 1973-88.

Year	Type of agreement	Key elements
1973	Fisheries cooperation	Technical assistance, joint research, joint ventures (never implemented), training
1980	Fisheries cooperation	Technical assistance, joint krill stock assessment, possibility of joint krill fishing venture
1980	Joint venture agreement	Soviet vessels to operate under Argentine flag (never implemented)
1985	Vessel repair agreement	Tandanor Shipyard to repair Soviet fishing vessels
1986	Fisheries access and cooperation	Licensing fees, training, 180,000 t fish allocation
1987	Joint venture agreement	Soviets to purchase an amount of fish equal to 30 percent of the value of their catch

pay the higher prices for fishing licenses. Consequently, the Soviets withdrew their fleet on 1 April 1968 when the Argentine Navy began to strictly enforce the new regulations. Most Soviet vessels moved to the north or east of the Argentine 200-mile zone, but some Soviet captains—contrary to directions from the Soviet Ministry of Fisheries—apparently returned to the highly productive Argentine waters, resulting in several vessel seizures.

Enforcement Incidents, 1968

Argentine-Soviet tensions reached a peak in June 1968, when an Argentine Naval vessel fired upon and struck the Soviet trawler *Golfstrim*, forcing it to stop for boarding and seizure. (Another Soviet trawler, the *Pavlovo*, was also seized in the same incident, but escaped during a storm that developed while the Argentine Navy was escorting it to the port of Buenos Aires.) The Soviets strongly protested the incident, claiming that the vessel was seized outside the Argentine 200-mile zone, off the coast of Uruguay, and demanded compensation for the damage to the trawler. The Soviet appeal, however, went largely ignored. The vessel was held at Buenos Aires until late July 1968, when Soviet "commercial agents" paid a $25,000 fine and an additional $3,000 in port charges. (The Soviet Government, as it did in purchasing fishing licenses, used "commercial agents" (rather than governmental channels) to resolve the dispute, to avoid recognizing Argentine jurisdiction.) As a result of the strict Argentine enforcement program, the Soviet catch in the Southwest Atlantic declined by more than two-thirds in 1968, to only 190,000 t (Fig. 3 and Table 3). The Soviet fleet apparently ceased most fishing activity in Argentine waters following the *Golfstrim* incident. Argentine fishermen continued to complain sporadically about Soviet fishing inside the Argentine zone during 1969-70, but the charges were disputed by the Argentine Navy.

Continued Soviet Interest, 1970's

The Soviets continued to be interested in rich Argentine grounds as a potential resource for their rapidly expanding fishing fleet even after withdrawing their vessels in 1968. Soviet officials correctly perceived the waters off Argentina as one of the world's last remaining large underutilized fishing grounds. Their research and brief fishing experiences correctly identified the Patagonian Shelf as an ideal ground for the Soviet fleet. Soviet distant-water trawlers were ideally suited to harvest the demersal resources occurring on the Patagonian shelf. After being expelled from Argentine waters, the Soviets reported some success by moving northward. The Soviets were able to increase their Southwest Atlantic catch to over 400,000 t in 1970, primarily by increasing effort off the coast of Brazil. This prompted Brazil to declare its own 200-mile zone in 1970. As a result, Soviet catches in the Southwest Atlantic declined to only 26,000 t by 1971. Soviet Southwest Atlantic catches remained at low levels until 1983.

Fisheries Cooperation, 1973-74

Soviet fishery officials attempted to resume contacts with the Argentine Government after Juan Perón returned to the Presidency in 1973. The Soviets dispatched a delegation of high-ranking fishery officials to Buenos Aires in August 1974 for negotiations. The Soviet delegation visited the port of Punta Quilla (along Argentina's central coast) and expressed an interest in fishing stocks off Santa Cruz Province. In return, the Soviets offered technology to assist in the development of the Argentine fishing industry. The two governments initialed an agreement which provided for a joint stock assessment project south of lat. 42°S[1], a training program for Argentine fishermen, technical and economic assistance for the construction of a fishing port in southern Argentina, and the eventual formation of a joint fishing venture (Table 4). The agreement proved to be of little consequence. No actual fishing resulted from this accord, nor were any joint ventures actually formed, largely because (following the death of her husband, Juan Perón) President Isabel de Perón curtailed most commercial contacts with the Soviet Union. The Soviets did, however, expand their Antarctic fishery south of Argentina, and in 1974 reported a significant krill catch (72,000 t) for the first time (Table 5, 6).

Argentina claims the Antarctic sector south of lat. 60°S, and between long. 25°W and 74°W, an area which includes the Soviets' most important krill fishery. Argentina is, however, a Consultative Party to the Antarctic Treaty (ATCP), a multilateral regime under which a claimant state's claims are frozen (i.e., the claimant state's actions will have no bearing on its claim as long as the treaty is in force). The Soviet Union, which is also an ATCP, is allowed to harvest krill under the auspices of an agreement complementary to the Antarctic Treaty, the Convention for the Conservation of Living Marine Antarctic Resources (CCLMAR).

[1]The southern latitudes specified in this and subsequent agreements with the Soviets are significant as few Argentine fishermen operate South of lat. 42°S. Consequently, the authorized Soviet activity would not compete with domestic fishermen.

Table 5.—The Soviet Union Antarctic krill catch by FAO area, 1970-86.

Year	Catch by FAO area (1,000 t) 41	48[1]	58	88	Total
1970					
1971					
1972					
1973					
1974		22.7			22.7
1975		38.9			38.9
1976		0.5			0.5
1977		99.8	1.9	3.3	105.0
1978		89.8	26.5		116.3
1979		321.2	28.0	0.6	349.8
1980	0.2	356.8	83.8		440.8
1981		285.1	132.2	3.1	420.4
1982		368.2	119.4	4.1	491.7
1983		128.8	45.6	5.9	180.3
1984		62.3	12.0	Negl.	74.3
1985		146.9	3.7		150.6
1986		366.7	10.6	1.9	379.2
1987		264.5	25.6	0.3	290.4

[1]FAO Area 48 is the area directly south of Argentina and the South Atlantic

Table 6.—The Soviet southwest Atlantic fish catch (FAO area 41) by species, 1980-86.

Species	Catch (1,000 t) 1980	1981	1982	1983	1984	1985	1986	1987
Grenadiers	0.2			18.1	31.0	8.7	15.0	69.5
Squids	0.9	0.4	18.2	21.3	15.6	38.5	36.8	47.9
Southern blue whiting	21.4	16.8		24.2	10.2	16.2	2.8	33.6
Argentine hake	3.5	Negl.	0.4	1.7	0.2	0.5	0.2	4.0
Other gadiformes					Negl.		0.2	0.5
Argentine anchovy	0.6	Negl.		0.1	0.7	0.1	Negl.	0.5
Patagonian toothfish								0.4
Other	3.0		0.5	0.6	0.2	0.5	2.3	12.1
Antarctic silverfish						6.0	19.8	
Antarctic krill	0.2							
Total	27.7	17.2	19.0	66.0	58.0	70.9	77.1	168.5

Table 7.—Argentine exports to and imports from the Soviet Union, 1964-87.

Year	Trade (US$ million) Exports	Imports	Percent of exports shipped to the USSR
1964	15.1	2.9	1.0
1965	81.9	17.9	5.5
1966	88.1	18.2	4.8
1967	19.5	7.2	1.3
1968	17.6	4.9	1.3
1969	21.3	8.9	1.3
1970	27.3	3.1	1.5
1971	30.3	3.9	1.7
1972	24.1	2.6	1.2
1973	83.1	7.0	2.5
1974	211.1	10.9	5.4
1975	288.3	22.0	9.7
1976	219.1	12.8	5.6
1977	210.7	20.3	3.7
1978	385.5	11.1	6.0
1979	415.3	30.7	5.3
1980	1,614.2	14.6	20.1
1981	2,963.2	32.4	32.4
1982	1,586.4	33.3	20.8
1983	1,635.9	31.5	20.9
1984	1,187.8	35.6	14.7
1985	1,212.7	41.9	14.4
1986	208.8	59.2	3.0
1987[1]	634.0	92.9	9.9

[1]January-October only.

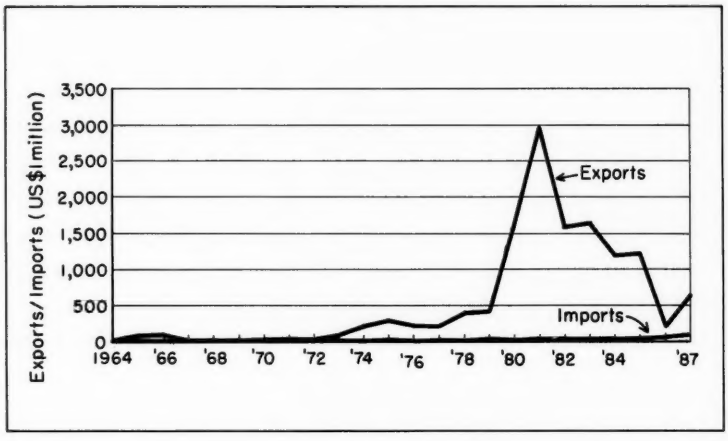

Figure 4.—Argentine exports to and imports from the Soviet Union, 1964-87.

Enforcement Incidents, 1977

Soviet-Argentine fishery relations took a turn for the worse in 1977 when the Soviets apparently increased fishing effort in the Southwest Atlantic without concluding an access agreement with Argentina. (The Soviets reported a slight catch increase to FAO, but the size of the Soviet Southwest Atlantic presence in 1977 indicates that the actual catch increase may have been much larger.) The military regime that had ousted President Isabel de Perón in 1976 responded to the Soviet fishing activity by intensifying enforcement efforts, resulting in the most serious fishery incident between the two countries. During a 2-week period in September-October 1977, the Argentine Navy seized seven Soviet trawlers and two Bulgarian vessels fishing inside the Argentine 200-mile zone. According to Argentine press reports, 12 other vessels managed to evade capture. Some reports indicate that as many as 30 foreign (mostly Soviet) vessels may have been operating in Argentine waters for 6 weeks prior to the seizures.

It is not clear why the Soviets were willing to risk alienating the South American government with which it had the best relations by violating its fishing regulations. The United States had sharply reduced Soviet fishing off its coasts in 1977 and the Soviets needed to find alternative grounds. The Soviets may have thought that Argentina would prove tolerant of their fishing activities, because the Soviet Union had become an important buyer of Argentine agricultural commodities by 1977 (Table 7, Fig. 4). The Argentine Government, however, formally protested the presence of

Soviet trawlers in Argentine waters. The Soviets, in turn, warned the Argentine Government that the continuation of good bilateral relations depended upon the favorable resolution of the matter. Argentine authorities apparently ignored the Soviet warning, fining the vessel masters $100,000 each—the maximum possible under Argentine law—and confiscating their catches, which included 2,600 t of fish and 85 t of fishmeal. The confiscated fish was sold to the Bajamar company of Spain, and was subsequently shipped to Spain by a Soviet refrigerated cargo vessel. The 1977 seizures proved to be the nadir of Argentine-Soviet fishery relations. Argentina has not seized any Soviet fishing vessels since the 1977 incidents, but it is not known whether that is because of a lack of illegal Soviet activity or an Argentine desire to avoid disruption of their important commercial relationship with the Soviets. The Soviet Union, in some years, has been Argentina's principal trading partner. In 1982, for example, because of the grain embargo which had been imposed on the USSR by the United States in 1980, the Soviet Union purchased nearly 80 percent of Argentina's agricultural exports. Argentina's trade surplus with the Soviet Union in 1982 was over $3.1 billion.

Renewed Cooperation, 1980-83

Argentine and Soviet officials continued to discuss fishery issues even after the 1977 confrontation. The increasing importance of Soviet grain purchases to Argentine farmers (Table 7) proved strong enough to override the Argentine military's virulent anticommunism. As a result of these negotiations, the two countries signed, in March 1980, a new fisheries cooperation agreement that was very similar to the 1974 accord (Table 7). The new cooperation agreement provided for a krill stock assesssment south of lat. 46°S, and for the eventual establishment of a joint krill fishing venture. The Soviets had been expanding their Antarctic krill fishery since 1974. Soviet krill catches exceeded 100,000 t for the first time in 1977, and by 1980 had reached over 440,000 t, most of which was taken in Antarctic waters directly south of Argentina (Table 5). Argentine officials apparently hoped that the Soviets would share their krill processing technology, so Argentina could take advantage of that immense resource. The joint krill fishing venture was officially authorized by the Argentine Government on 8 April 1982 (just 1 week after the Argentine invasion of the Falklands). The agreement specified that 10 Soviet vessels would operate south of lat. 46°S under the Argentine flag. An Argentine delegation traveled to Moscow in July 1983 to discuss the actual formation of the joint ventures. The Soviets, however, reportedly tried to renegotiate the deal to enable them to operate their vessels under the Soviet flag, and the negotiations broke down. No joint company was formed and the Soviets were still not allowed to fish off Argentina.

Falklands Conflict, 1982

Soviet-Argentine fishery relations changed dramatically after 1982, as a result of the Falklands conflict with the United Kingdom (U.K.). After recapturing the Falklands in mid-1982, the United Kingdom established a 150-mile Falkland Islands Protection Zone (FIPZ) (see map). The British took no action to prevent foreign fishing in the zone, but they did insist that Argentine fishermen apply for permits—which would have been a de facto recognition of British jurisdiction. The Argentines refused to do so, and were thus denied access. The British also excluded Argentine enforcement vessels. As a result, fishemen from many countries—no longer hampered by Argentine regulations—began fishing off the Falklands. The Poles and the Soviets became the primary beneficiaries of the British laissez-faire policy. Poland, which has been denied access to U.S. grounds since the imposition of martial law, initiated a massive squid fishery off the Falklands. The Soviets initiated a major fishery for squid, southern blue whiting, and other demersal species. By 1985, about 60 Soviet stern factory trawlers were operating in the Southwest Atlantic (mostly off the Falklands), and reported a catch of almost 71,000 t, a large share of which was squid (Table 6). (The 2,500-gross registered ton (GRT) class of Soviet trawlers that operated off the Falklands each have the capacity to land 8,000-10,000 t of fish per year, which leads some to conclude that the Soviets were substantially under-reporting their catches.) The Soviet fleet did not have access to repair facilities in the South Atlantic, however, and consequently its representatives signed a service contract with the Tandanor Shipyard in Buenos Aires, which is owned by the Argentine Ministry of Defense (Table 4). The Defense Ministry reportedly pursued the deal to cover operating expenses and compensate for cuts in the

The Argentine 200-mile zone. Note that the FIPZ has been supplanted by the FICZ. The Falkland Islands, administered by the United Kingdom, are claimed by Argentina.

military budget implemented by the civilian administration of President Raul Alfonsín. Three vessels, the *Van Gogh*, the *Gletcher*, and the *Ritza*, were repaired at the Tandanor Shipyard in early 1985, and the shipyard has reportedly been full of Soviet fishing vessels since that time.

Argentine Diplomatic Initiatives, 1985-86

Argentine officials became increasingly concerned with the successful implementation of the FIPZ by the British. The Argentines had various objections to the British action. First, the British effectively prevented Argentine fishermen from fishing the rich grounds off the Falklands. British enforcement patrols confronted any Argentine vessel—military or civilian—entering the FIPZ. A report released in September 1988 by the Programa de Asistencia al Poder Legislativa stated that 54 percent of the fishery resources of the Patagonian Shelf are located around the Falklands. The report asserted that the increased foreign fishing off the Falklands was at the expense of the Argentine catch. Some observers disagree, however, pointing out that very little hake (which constitutes about 70 percent of the Argentine catch) is found near the Falklands.

Second, the massive foreign fishing effort posed a potential threat to stocks, which Argentine authorities could no longer protest. Third, the rising foreign catch around the Falklands competed with Argentine exports of similar species, adversely affecting prices in important foreign markets.

The Argentine Government, faced with the above fisheries situation and—more importantly—actively attempting to gain international recognition for its Falklands claim, contacted countries fishing off the Falklands in an effort to negotiate bilateral fishery agreements. Most distant-water countries contacted by the Argentine Government were benefitting from the wide-open Falklands fishery, and as a result, showed little interest in the Argentine initiative. Poland and Spain had initiated major trawl fisheries off the Falklands, and several Asian countries were steadily increasing jigging and other fishing operations.

Bilateral Access Agreements, 1986

Only two countries responded positively to the Argentine initiative: The Soviet Union and Bulgaria, which have tacitly supported the Argentine claim to the Falklands. (The Soviets have generally supported Argentina on U.N. resolutions concerning the Falklands. Shortly after the Argentine invasion of the archipelago, however, the Soviets abstained from a U.N. Security Council initiative condemning the Argentine action. The Argentine Junta had hoped for a Soviet veto of the measure, but the Soviets declined to exercise their veto because to do so would have meant condoning the use of military force.)

As a result, after excluding Soviet fishermen from Argentine waters for 18 years, the Argentine Government, in July 1986, initialed an agreement allowing the Soviet fishing fleet to resume operations inside Argentina's 200-mile zone (Table 4).

Agreement Provisions

Under the terms of the agreement, 18 Soviet stern factory trawlers would be allowed to catch up to 180,000 t annually. The Argentines also signed a similar agreement with Bulgaria which permitted 6-8 trawlers to catch 80,000 t annually. The Bulgarian fleet often operates closely with the Soviets, who share research results and support services. These vessels were prohibited from operating north of lat. 46°S, and from catching shellfish and hake (species upon which Argentina's domestic fishing industry is highly dependent). To enforce these provisions, the agreement stipulated that all Soviet vessels operating in Argentine waters were prohibited from fishing without an Argentine inspector on board. The 2-year agreement required the Soviets to pay a 3 percent licensing fee and to purchase a quantity of Argentine-processed fishery products equal in value to 30 percent of the value of the Soviet catch in Argentine waters. The agreement also provided for the training of Argentine fishermen aboard the Soviet vessels; 10 percent of the crews on these ships were to be Argentine citizens. Although the Soviets did pay the salaries of the proper number of Argentine fishermen, some observers reported that very few Argentine fishermen were actually trained on board the Soviet trawlers during the first year of the agreement. To accommodate the support needs of the Soviet fleet operating so far from home, the accord allows the Soviets to use Argentine ports for crew exchanges and resupply and maintenance activities.

The Domestic Debate

Despite the seemingly favorable terms obtained by the Argentine Government, the bilateral agreement with the Soviets was sharply criticized by various groups in Argentina. Some individuals, such as former Argentine President Arturo Frondizi, were concerned over the security implications. The most intense criticism, however, has come from the Argentine fishing industry. Argentine fishermen, like fishermen in most other countries, resented their government authorizing foreign fishing. Many thought that the intensive fishing methods practiced by the Soviet fleet would endanger Argentina's fishery resources. (In order to operate their large stern trawlers profitably, the Soviet distant-water fleet needs to achieve high yields. This often necessitates fishing a given area intensively, taking juvenile as well as adult fish to maximize the catch, and then moving on when yields fall. The fleet then returns to the area in 5 or 6 years, if the fish population recovers.)

Other Argentines claimed that this fear was unfounded, as the agreement in fact provided for a reduction of the Soviet fishing effort on the Patagonian Shelf. (As mentioned earlier, the Soviets had been operating more than 60 vessels off the Falklands, while under the terms of the new agreement, only 18 would be permitted inside the Argentine 200-mile zone at any one time.) Despite the domestic criticisms, the Government decided to proceed with the agreement. President Alfonsín traveled to Moscow to sign

the accord in October 1986. In protest, the Cámara de Armadores de Buques Pesqueros de Altura (CAPeCA—the Association of High-seas Fishing Vessel Owners) called a 14-hour strike. Because the agreement was so controversial, the ratification process in the Argentine Chamber of Deputies proved to be lengthy and was characterized by heated, often acrimonious debates.

British Establish Falklands Management Zone, 1986-87

The domestic debate over the Soviet agreement ended on 29 October 1986, when the British announced that, as of 1 February 1987, they would enforce a 150-mile Falkland Islands Interim Conservation and Management Zone (FICZ), requiring all foreign fishermen to purchase licenses. The Falkland Islands Office (FIO) in London subsequently announced that countries wishing to fish off the Falklands should apply by 5 December 1986, so licenses could be issued by 15 December. Fees ranged from $18-135 per vessel Gross Registered Ton (GRT) for trawlers to $293 per vessel GRT for squid jiggers. The revenue generated by these fees gave a massive boost to the Falklands economy during 1987, resulting in a 210 percent increase in the islands' Gross Domestic Product.

Argentina Ratifies Agreements, 1986

Argentine legislators realized that if they did not quickly ratify the Soviet agreement, the Soviets might buy licenses from the Falkland Islands Government (FIG)—thus acknowledging de facto jurisdiction of the United Kingdom. As a result, the Chamber of Deputies unanimously approved both the Soviet and Bulgarian fishery cooperation agreements on 31 October 1986. Argentine officials had hoped to negotiate agreements with the noncommunist countries fishing off the Falklands, but were unable to do so. The Soviet Union and Bulgaria were the only countries to add some credibility to Argentina's Falklands claim, as Argentina's fishing agreements with them theoretically allowed the Soviets and Bulgarians to fish off the Falklands with Argentine—and not British—permission. Fishermen of all other nationalities operating off the Falklands, however, purchased FIG licenses and the continued Argentine efforts to negotiate bilateral fishery agreements achieved little. (Taiwan reportedly expressed an interest in an agreement, but Argentine officials demurred, as they do not recognize Taiwan.) The governments involved insisted that they were not recognizing British sovereignty and that the purchase of licenses by fishing companies was a purely commercial decision. The Argentine Government continues to pursue fishery agreements with countries fishing in the South Atlantic. The Argentine press reported contacts with Japan and Spain during 1988.

Soviet Fishing, 1987-88

The Soviets commenced fishing activities in Argentine waters in May 1987. The Soviet catch during the first 12 months of the bilateral agreement (May 1987-April 1988) according to official Argentine Government statistics, totaled 180,000 tons (Table 8). The most important species were various demersal fishes: Patagonian toothfish (73,600 t), grenadiers (41,400 t), southern blue whiting (40,500 t), and squid (11,200 t) (Table 9).

Five Argentine fish processing companies signed an agreement in April 1987 (Table 4), to supply the Soviets with processed fish, as provided for in the bilateral agreement. These companies included: Argenpez, Bajamar, Frigorífico Gepa, Pesquera Argentina del Sur, and Pesquera Cono del Sur. Two other companies, Pesquera Santa Elena and Pesquera del Atlántica, were also expected to participate. It was agreed that the processed fish would be marketed in the Soviet Union, so as not to compete with Argentine products in Europe and other traditional foreign markets for Argentine fishery products. During the first 9 months of the agreement, Bajamar was the main company supplying the Soviets. Frigorífico Gepa had reportedly gone out of business by mid-1988, but most companies supplying fish to the Soviets were doing

Table 8.—Soviet fish catch in Argentine waters by Species, 1987[1].

Species	Quantity (1,000 t)
Patagonian grenadier	31.4
Grenadier	17.6
Southern blue whiting	17.3
Squid	4.8
Antarctic hake	1.1
Argentine hake	1.1
Native cod	0.6
Patagonian toothfish	0.6
Kingklip	0.3
Rays	0.2
Other	1.8
Total	76.8

[1]Covers catch in Argentine waters during the first 6 months of the bilateral agreement, June-November 1987.

Table 9.—Names of marine species commonly found in Argentine waters and caught by Soviet fishing vessels.

Spanish name	English name	Scientific name
Abadejo	Kingklip	*Genypterus blacodes*
Anchoita	Argentine anchovy	*Engraulis anchoita*
Bacalao austral	Marid or native cod	*Saliota australis*
Brótola	Squirrel hake	*Urophysis brasiliensis*
Calamar	Common squids	*Loligo* spp.
Grenadero	Grenadier	*Macruronus* spp.
Krill	Antarctic krill	*Euphausia superba*
Merluza austral	Antarctic hake	*Merluccius australis*
Merluza de cola	Patagonian grenadier	*Macruronus magellicanus*
Merluza commun	Argentine hake	*Merluccius hubbsi*
Merluza negra	Patagonian toothfish	*Dissosticus eleginoides*
Nototenia	Southern cod	*Notothenia* sp.
Palometa	Pompano	*Parona signata*
Pampanito	Butterfish/Pomfret	*Stromateus maculatus*
Polaca argentina	Southern blue whiting	*Micrmestisius australis*
Rubio	South Atlantic rockfish	*Helicolenus dactylopterus*

so through Bajamar. Estimates of the value of the Soviet catch during the first 6 months of operations indicate that Soviet purchases were on line with the 30 percent purchase requirement (Table 10). Details on Soviet purchases of Argentine fishery products during the first full year of the agreement were not yet available, but purchases through the first 9 months of the agreement totaled over $15 million. The Soviets paid for the fish with hard currency, reportedly providing 90 percent up front.

Table 10.—Value of the fish processed by Soviet vessels operating in Argentine waters, May-November 1987.

Species and product form	Quantity (t)	Value[1] (US$1,000)
Patagonian grenadier		
Tronco	15,477.6	6,191.1
Whole	1,109.8	332.9
Headed/gutted	1,079.8	439.9
Other	305.2	106.8
Grenadier		
Headed/gutted	4,861.1	2,187.5
Tronco	2,470.9	1,111.9
Roe	35.2	70.3
Fillets	0.8	0.4
Southern blue whiting		
Headed/gutted	2,838.0	1,419.0
Loins	1,915.6	1,915.6
Whole	1,304.8	391.4
Tronco	824.6	412.3
Other	596.3	208.7
Fillets	414.8	331.8
Fishmeal	6,552.8	1,965.9
Squid		
Tube	1,405.1	2,529.1
Whole	798.0	558.6
Fillets	461.3	645.8
Tentacles	407.0	162.4
Antarctic hake		
Fillets	244.9	372.5
Tronco	212.6	327.0
Headed/gutted	89.6	147.3
Argentine hake		
Fillets	113.1	124.9
Headed/gutted	107.0	64.2
Tronco	264.7	158.8
Fish oil	304.8	112.8
Entrails	295.6	NA
Patagonian toothfish		
Headed/gutted	97.2	48.6
Fillets	81.8	69.6
Tronco	16.0	8.0
Native cod		
Headed/gutted	146.8	205.5
Tronco	36.2	43.1
Fillets	11.6	23.2
Kingklip		
Tronco	56.8	79.6
Fillets	23.4	46.5
Whole	22.7	11.3
Headed/gutted	0.8	1.4
Squirrel hake		
Headed/gutted	12.8	9.0
Roe	10.6	21.2
Southern cod		
Headed/gutted	7.9	4.0
Other	61.7	29.1
Total	45,076.3	22,889.0

[1]Values are estimates, and merely provide a general idea of the value of the Soviet catch.

The Soviets have primarily used the port facilities at Punta Quilla (see map), but are also allowed to use the facilities at Buenos Aires, Caleta Oliva, Comodoro Rivadavia, Puerto Deseado, Rio Gallegos, San Antonio Este, San Julian, and Ushuaia. In February 1988, Soviet officials expressed interest in developing Bahia Blanca as a modern fishing port. The Soviets apparently wish to use the repair facilities at that port, and negotiations for a port development project were scheduled for August 1988. According to press reports, the Argentine Government had approved the use of Bahia Blanca for 10 Soviet vessels, which were to land an estimated 40,000 t of fish at that port. These reports, however, have been denied by the Argentine Government.

Reports of "irregularities" in Soviet practices under the fishing agreement have been widespread in the Argentine press since the Soviets commenced fishing activities in May 1987. Reported irregularities have included the following:

Polish transshipments: Argentine fishermen alleged that a Soviet vessel operating off Argentina loaded a cargo of processed fish from a Polish factory ship that had been fishing in the FICZ under FIG license, which was apparently a violation of the 1986 Argentine-Soviet bilateral agreement. Soviet Foreign Minister Edward Shevardnadze, during his October 1987 visit to Argentina, denied any knowledge of the incident.

Argentine labor: Argentine dissatisfaction with the agreement flared up again later in 1987, when the Soviets landed their first shipment of fish at the southern port of Punta Quilla. Local stevedores were angered by the Soviet refusal to use Argentine labor to unload the cargo. The Soviet insistence on using their own workers, however, was not a violation of the bilateral agreement.

Argentine inspectors: The Argentine inspectors aboard the Soviet and Bulgarian vessels have reported various technical violations such as the use of double nets, thus reducing the effective size of the mesh from the allowable 100 mm to only 60 mm. This practice has caused an uproar among Argentine fishermen, because such small mesh retains juvenile as well as adult fish, thus endangering the resource. Argentine inspectors have also reported difficulty in obtaining catch data from the vessel captains and in obtaining access to radios for reporting their observations. Most of these complaints, however, came from inspectors on board the Bulgarian—and not the Soviet—vessels.

Export sales: Argentine businessmen have also claimed that a Soviet-Spanish joint venture, SOVISPAN, has marketed some of the fish purchased by the Soviets from Argentine processors in Greece (the seventh most important market for Argentine fishing companies in 1987), which would be another violation of the agreement. These activities by the Soviets would be particularly disturbing to Argentine fishermen, as the Argentine fishing industry is highly dependent on export markets (due to the limited domestic demand for fish).

Vessel registration: According to press reports of May 1988, the Naval Prefecture has licensed 29 Soviet vessels, 11 more than the 18 allowed by the original agreement. Critical press reports claimed that the Alfonsín Administration had overstepped its authority and had increased the Soviets' catch allotment to almost 300,000 t without consulting the Chamber of Deputies. These same press reports claimed that as many as 48 Soviet vessels might be operating in Argentine waters before the current agreement expired in May 1989. The companies participating in the joint ventures with the Soviets, however, insist that the Soviets never operated more than 18 vessels at a given time. The additional vessels licensed enable a full fleet of 18 vessels to operate at all times, as they could rotate with vessels in need of repairs or supplies.

Political Controversy

The opposition Justicialist (Peronist) Party has tried to politicize the

fishing agreement, possibly because of the upcoming (14 May 1989) presidential election. Peronists have widely criticized the Alfonsín Administration for its management of the bilateral fishing agreement. One Peronist legislator complained that, despite the reports of transgressions by the on-board inspectors, the Alfonsín Administration has taken no administrative action against the Soviets (or Bulgarians). The Peronist Vice-Governor of Buenos Aires, Luis María Macaya, claims that Soviet and other foreign vessels are operating illegally less than 100 miles from Mar del Plata, Argentina's primary fishing port, and causing "irreparable damage" to the fishery resource. Other politicians have spoken against the fishing agreement as well. Former Argentine President Arturo Frondizi opposes the agreement because it gives the Soviets access to Argentine ports. Eight Peronist members of the National Chamber of Deputies sponsored, in May 1988, two bills demanding that the Alfonsín Administration provide better information about new developments and changes in the fishing agreement with the Soviets. The bills would have required the President to report on: 1) Whether the Soviets were supporting the Argentine claim to the Falklands by fishing in the FICZ without buying FIG licenses, 2) the names of the Argentine companies that have formed joint ventures with the Soviets and the criteria used in their selection, 3) Soviet catch statistics, 4) the names of the Soviet vessels that have been registered with the Naval Prefecture, 5) whether the Soviets have been authorized to catch as much as 290,000 t, and 6) whether the Soviets have paid the correct fees for their fishing licenses. The bills were defeated.

CAPeCA prepared a report in late 1988 acknowledging that the Soviets had complied with the terms of the accord. The report does stress, however, a significant difference between Soviet and Bulgarian compliance with the terms of the treaties. CAPeCA notes repeated Bulgarian violations and demands that the agreement with Bulgaria be allowed to expire. Nevertheless, CAPeCA, which has always been vehemently opposed to the Soviet agreement, remained opposed to the continuation or expansion of the current accord, fearing a depletion of Argentina's fishery resources. The CAPeCA report stressed that large-scale studies of the fishery resources on the Patagonian Shelf are needed before Argentina permits any further foreign fishing. Not surprisingly, they also advocated the expansion of the domestic fishing industry before any more foreign fishermen are allowed to operate in Argentine waters.

Despite widespread criticism of the Soviet fisheries agreement, not all Argentines oppose it. Bajamar and the other companies involved in joint ventures with the Soviets prepared a report in March 1988, depicting the agreement in a very positive light. The report addresses many of the criticisms leveled against the Soviets in the press. Some press reports, for example, had claimed that the Soviets were required to buy a quantity of Argentine processed fish (product weight) equivalent to 30 percent of the catch (live weight). The report points out that the joint venture agreement between the Soviets and the companies supplying fish to them clearly requires that the Soviet purchases equal 30 percent of the value of the catch—not of the quantity. According to the joint venture partners, Soviet purchases actually exceeded 30 percent of the value of their catch, totaling 15,000 t (through 31 December 1987), valued at $15 million. This product was processed by 19 Argentine companies, and was mostly supplied to the Soviets through their most active joint venture partner, Bajamar. The report also provides details on the overall benefits of the agreement to the Argentine economy. During the first 9 months of the agreement, Argentina received $22.5 million in foreign exchange from Soviet payments for purchases of Argentine fishery products, licensing fees, wages for Argentine fishermen working on Soviet vessels, port charges at Santa Cruz and other ports, supplies for the vessels and vessel services and repairs (Table 11).

Table 11.—Foreign exchange generated for Argentina by the Soviet fishing agreement, May 1987-March 1988[1].

Soviet expenses	Amount (US$1,000)
Purchases of Argentine fish	$14,475
Licensing fees	1,000
Wages for Argentine crew	1,200
Port charges	
Santa Cruz	1,120
Other ports	1,070
Port supplies	
Santa Cruz	950
Other ports	600
Vessel repairs	815
Spending by Soviet personnel	515
Other miscellaneous expenses	400
Administrative costs	385
Total	$22,530

[1]This data is for a 9-month period only. Total foreign exchange expenditures for the first 12-month period were projected to be $30 million. Total costs to the Soviets for the fish they caught (not including the fish purchased from Argentine companies) may amount to $10 million of that total, which with a 12-month catch of 180,000 t would be a hard-currency cost of about $55/t. Ruble operating costs are not known.

Agreement Renewed

Argentine Undersecretary for Fisheries, Luis Jaimes, announced on 30 October 1988 that Argentina planned to renew the Soviet bilateral agreement for a third year, through 18 March 1990. The renewal occurred under the provision of the original 2-year agreement stipulating that if neither government objected to the agreement's renewal 6 months before it was set to expire, it would automatically continue for another year.

Conclusions

The Soviet Union has patiently persisted in its efforts to develop a relationship with Argentina which would permit access to the rich fishing grounds of the Patagonian shelf. The brief Soviet fishery conducted in the late 1960's demonstrated to the Soviets that sizeable catches could be achieved off Argentina. Soviet interest in an access agreement can be gauged by their persistence in pursuing negotiations despite being confronted with numerous obstacles. The Soviets have encountered repeated difficulties in building that relationship, including the traditional Argentine hostility toward foreign exploitation of its natural resouces, extended jurisdiction,

military action against and heavy fines for fishing vessels operating illegally, virulently anti-communist governments, suspicion of military officers toward communist countries, and costly hard currency payments.

It was not until Argentina's disastrous confrontation with the British over the Falklands, however, that Argentine officials even began to seriously consider an access agreement with the Soviets. Nevertheless, the Argentines still demanded tough terms for Soviet access (including marketing limitations, development assistance, employment of Argentine workers, purchase commitments, etc.). The Soviets, having persevered in their diplomatic efforts for 20 years, were forced to choose between Argentina's costly terms, the purchase of FIG licenses, or a withdrawal from the southwest Atlantic. The Soviets finally acceded to the Argentine terms. Others countries (Germany, Japan, Korea, Poland, and Spain) which had been operating off the Falklands prior to the declaration of the British FICZ have generally been unresponsive to persistent Argentine diplomatic efforts aimed at negotiating access agreements. These countries maintain that the stringent demands of the Argentine Government would make operations off Argentina unprofitable.

The Argentine-Soviet relationship seems to have proven beneficial to both countries. The benefits to Argentina, however, are easier to evaluate than those achieved by the Soviets. Probably the most important benefit for Argentina is diplomatic in nature: The agreement gives at least some international recognition for Argentina's Falklands claim. Argentina had hoped to negotiate agreements with the non-communist countries fishing off the Falklands, but were only successful in doing so with the Soviets and the Bulgarians. As a result, the Argentines are probably tied more closely to the Soviets than they would like.

In trade relations, the fisheries agreement was one way of placating Soviet demands for a more equitable economic relationship. The Soviets are a major purchaser of Argentine agricultural goods, while Argentina buys little from the Soviets in return (Fig. 4, Table 7). The importance of this trade requires the Argentines to make some efforts to respond to Soviet demands for a more equitable relationship. A fisheries allocation in an area not heavily utilized by Argentine fishermen was a relatively painless concession for the Argentines.

The Soviets also provide a variety of economic benefits, including the payments to the Argentine Government, fishing companies, and workers as well as development assistance. The Soviet payments (including purchases of Argentine fish) totaled about $30 million in the first year of the agreement (Table 11). These payments to economically depressed Argentina have provided badly needed foreign exchange and have proven profitable to the companies working with the Soviets.

Soviet motives in pursuing the Argentine relationship are less clear-cut. The principal Soviet motivation appears to be obtaining allocations for its distant-water fleet, but the actual economic calculation as to the true economic benefits are difficult to calculate. The Argentine agreement appears to benefit the Soviets in three principal ways: Allocations and diplomatic and economic/commercial advantages.

The agreement provides an allocation of 180,000 t of demersal fish and squid. The enormity of the Soviet distant-water fleet necessitates that they maintain access to fishing grounds off the coasts of other countries—which has proven to be increasingly difficult. The Soviets are especially interested in Argentine grounds because the demersal species occurring there can help offset declining catches of their most important demersal species—Alaska pollock. (Soviet catches of Alaska pollock dropped from 3.58 million t in 1986 to 3.42 million t in 1987.) The Argentine allocation is one of the largest received from any coastal country. The various demersal species (blue whiting, grenadiers, etc.) may become occasional substitutes for pollock in the Soviet market. The Soviet interest appears to be focused primarily on the fishery allocation. The fact that the Soviets have pursued an access agreement—even with virulently anti-communist Argentine governments in power—for 20 years suggests a fish allocation has been, and continues to be, their principal objective.

The fisheries agreement with Argentina was also in line with the general Soviet foreign policy goal of supporting developing countries on anti-colonial issues. While the nature of the Falklands/Malvinas issue is certainly debatable, it is portrayed by Moscow and Buenos Aires as a colonial issue.

The fisheries agreement is also in line with recent Soviet initiatives to broaden commercial and economic contacts in Latin America. The Soviet initiative has included efforts to sign fishery or fishery-related agreements with other Latin American countries, including Panama, Peru, and Uruguay. Latin America for years had been a backwater for the Soviet Union. Limited Soviet interests in the area and the hostility of many governments caused the Soviets to place a fairly low priority on relations with the region. The Soviets did not even maintain diplomatic relations with several countries. Expanded fishery contacts, as part of the new initiative, have the side benefit of expanding their information gathering capability. In previous years a fairly small number of Soviet diplomats were stationed in Latin America. With expanded diplomatic contacts, new commercial activity, and exchanges of crew members through ports in Argentina, Cuba, Panama, Peru, and Uruguay, a much greater number of Soviet nationals are now in the region, considerably expanding the Soviet capability to gather information as well as conduct covert activities.

The actual economic benefits of the Argentine agreement for the Soviet Union are difficult to assess. The Soviets are paying an exceedingly low licensing fee of only about $7 per ton. This would appear inexpensive compared to the $78 per ton for Pacific hake and $95 per ton for Alaska pollock that the United States charges foreign fishermen operating in the U.S.

EEZ. Several factors need to be taken into account, however, when evaluating the economic benefits to the Soviets.

First, most of the species taken off Argentina are less desirable than Pacific hake and Alaska pollock. The species taken by the Soviets in large quantity are not familiar to Soviet consumers, and fishermen report that one of the principal species, southern blue whiting, is frequently infested with parasites, further reducing its appeal to Soviet consumers. Second, Soviet operating costs off Argentina are high because of the great distance from Soviet ports.

Third, the agreement requires that many expenditures besides licensing fees be made in hard currency. The foreign currency costs alone are about $55 per ton. Note, however, that this figure does not include the substantial hard currency outlays required to purchase Argentine fish, as required by the bilateral agreement. The agreement also stipulates that the Soviets cannot resell the fish on the international market to recoup the hard currency payments. Without additional data on the overall Soviet operating costs, however, it is not possible to evaluate the economics of the Soviet operations off Argentina. While the economics of the Soviet operation are not fully known, one should remember that the countries operating commercial fisheries in the South Atlantic (the European Community, Japan, Korea, Spain, etc.) have all declined to sign similar arrangements with the Argentines.

The long-term outlook for the Soviet-Argentine fisheries relationship appears positive. The Argentines seem likely to continue the agreement considering the benefits accruing to them. In addition, having expended considerable diplomatic efforts in trying to sign agreements with various countries, the Argentines are less likely to eventually pull out of the only agreements they were able to conclude.

There are, however, some domestic political costs as the principal opposition party, the Peronists, have been critical of the agreement. (The political costs are somewhat reduced by the fact that the Argentine Congress does not have to approve future renewals of the agreement. Renewal merely requires inaction on the Government's part. Renewal requires neither debates in the Chamber of Deputies nor bilateral negotiations; all that is needed for the agreement to continue is for neither country to file a written objection to its continuation.) Despite this, Peronist Presidential candidate Carlos Saul Menem (who had enjoyed a 20 percent lead in the polls) does not seem to be predisposed to cancelling the agreement. Menem, in a December 1988 interview, expressed a desire for stronger commercial relations with the Soviets, which he already characterized as "very good." Nevertheless, even if Menem were opposed to the agreement, he would be powerless to cancel it before March 1991. The deadline for refusing renewal through that date is in October 1989, 2 months before Menem (or whoever is elected) is scheduled to be inaugurated. A Lame Duck Alfonsín Administration (which has already renewed the agreement once) would have nothing to lose politically and, as a result, would likely renew it for the 1990-91 period.

Ironically, if the agreement is terminated during the next few years, it may well be the Soviets who cancel it. Some observers maintain that the agreement was a last resort for the Soviet Fisheries Ministry. The terms demanded by Argentina—and granted by the Soviets—may have been among the most costly in the history of Soviet fisheries diplomacy, although the full cost of operating off Argentina cannot be determined. From the Soviet perspective, one of the most difficult requirements is that they have to pay for fishing rights (through licensing fees and fish purchases) with foreign currency. This is highly unusual for the Soviets. Other Soviet access agreements negotiated with developing countries have generally stipulated that the Soviets pay with a share of their catch, rather than foreign currency.

Most Soviet fishery agreements are with the developing countries. The Soviets also have, however, various access and cooperation agreements with Canada, Finland, Iceland, Japan, New Zealand, Norway, and Sweden. Most of the allocations received by the Soviets are obtained by offering reciprocal fishing rights, such as the agreement with Japan. The Soviets do obtain additional quantities of fish through over the side purchases from fishermen. These purchases are often in hard currency, but the Soviets are usually able to generate sufficient hard currency earnings from the resale of part of the product so that there are no net hard currency costs. For example, the Soviets currently buy Pacific hake over the side from U.S. fishermen for about $110 per ton and pollock for about $130 per ton. Unconfirmed reports suggest that part of the purchases are processed and exported, more than paying for the initial hard currency costs.

It is even more unusual that the Soviets have agreed to commit hard currency costs for purchases of fishery products which will primarily be marketed in their domestic market. The species taken off Argentina almost certainly will be marketed domestically, except for the squid. The squid catch, however, is only a small part of the take within Argentine waters (Table 8). As part of the terms of the agreement with Argentina, the Soviets have to limit catches of the most desired species in the Southwest Atlantic—hake. As a result, some observers have concluded that the Soviets only signed the agreement because there was no place else to fish; they had been effectively shut out of the Falklands fishery by the declaration of the FICZ (barring Soviet purchase of FIG licenses). It may well be, however, that the Soviets are able to combine the allocations off Argentina with their fishing outside of 200 miles (The Soviets use the port services at Montevideo for supply ships and fishing vessels not authorized to fish in Argentine waters. The Soviets signed a fisheries agreement with Uruguay in April 1987, but the agreement proved controversial in Uruguay and has not yet been ratified by Uruguay.) to produce fish at an acceptable price. Without

additional data on the economics of Soviet fishing in the South Atlantic, it is impossible to draw any firm conclusions on this question.

(Prepared by Don Jacobson, Foreign Affairs Assistant, and Dennis Weidner, Foreign Affairs Officer, Branch of Foreign Fisheries Analysis, National Marine Fisheries Service, NOAA, Washington, D.C. IFR/88-108.)

A Color Guide to the World's Lobsters

Another outstanding book spawned by a *Marine Fisheries Review* article is **"Lobsters of the World, an Illustrated Guide"** by Austin B. Williams, and with additional materials prepared by publisher Ian Dore. Williams' initial article was "Lobsters—identification, world distribution, and U.S. trade," published in issue number 2, 1986, of the MFR. The book is important because it makes widely available the series of excellent color photographs of lobster tails along with the illustrated key for identification of the lobster tails found in world trade. Combined, they greatly facilitate identification of lobsters for fishermen, fish wholesalers and purchasers, seafood inspectors, restauranteurs, and others.

In addition to Williams' fine and well illustrated article, Dore has included range maps for most species and a full-body color illustration of many of them to help facilitate identification. In addition, the original color tail photographs are reproduced in a larger format. Also, a Part 3 has been added providing supplementary information on other types of lobsters, including black and white drawings, size data, and vernacular names in many languages for species including various crayfishes, lobsterettes, rock lobsters, slipper lobsters, and langostinos. Bibliographic references are provided as well as general and scientific name indexes. An appendix provides a selective (noninclusive) list of lobsters and lobster-like species. Part 1, also added by Dore, discusses what a lobster is, the different types, their anatomy, how they are classified scientifically, commercial lobster nomenclature, warm and cold water lobster information, and describes how to use the book. Part 2 is Williams' article and key to lobsters. When scientists identify or classify lobsters they normally work with the whole animal, while the seafood trade often deals with tails only which, alone, are much more difficult to identify; thus, this book serves a very real need and gives global coverage of the major species traded; it also lists or describes certain others that might be confused with commercial forms. Hardbound, the 186-page volume is available now from Van Nostrand Reinhold, 7625 Empire Dr., Florence, KY 41042 at US$80.00.

An Illustrated Guide to the Tunas and Billfishes

Back in 1977 the *Marine Fisheries Review* published Witold Klawe's review "What is a Tuna?," which was both popular and widely cited. It also served as the basis for a book "**Tuna and Billfish—Fish Without a Country**," well illustrated with fine watercolors by marine artist George Mattson and with the text expanded by James Joseph, Witold Klawe, and Pat Murphy to present information on the species biology and life history, human commercial and recreational uses of them, and important aspects of research and management.

Now an augmented and much improved fourth edition of that book has been published by the Inter-American Tropical Tuna Commission. Considerably revised, it includes 28 full-page color plates of the various species, including 23 of Mattson's watercolors. The book is further enhanced by many other photographs, color species distribution maps, and line drawings of 61 species. Maps were prepared by Tamotsu Nakata and other art was by Kenneth S. Raymond, Henry M. Orr, Makoto Miyake, Sigeiti Hayashi, Harry and Christina Bremner, Joan Cooley, and Andrzej Lojszczyk. The cover photograph is a striking underwater color photograph of yellowfin tuna by NMFS scientist Bill High. The publication will likely be appreciated by anyone, professional or not, who has an interest in these species. The 69-page paperbound book also includes world records of the species and a bibliography, and it is available from "Tuna and Billfish Book," P.O. Box 271, La Jolla, CA 92038 for $15.75 postpaid.

Northeast Pacific, Bering Sea Fishes: Life History Notes

"**Species Synopses: Life Histories of Selected Fish and Shellfish of the Northeast Pacific and Bering Sea**", edited by Norman J. Wilimovsky, Lewis S. Incze, and S. J. Westrheim, has been published by the Washington Sea Grant Program and Fisheries Research Institute, University of Washington, 3716 Brooklyn Ave. N.E., Seattle, WA 98105. It presents a fine series of refereed review papers on life history aspects of several commercially important marine species which should be useful for fishery biologists and managers, oceanographers, and those doing related modelling work.

Species reviewed include the northern pink shrimp, *Pandalus borealis*; Pacific sand lance, *Ammodytes hexapterus*; Pacific herring, *Clupea harengus pallasi*; walleye pollock, *Theragra chalcogramma* (two articles discuss this species, separately, in the eastern Bering Sea and the Gulf of Alaska); market squid, *Loligo opalescens*; and Pacific halibut, *Hippoglossus stenolepis*. Information and literature is current up to about 1986–87 and includes some gray literature that may be difficult to find but still important from various NMFS research cruises. Paperbound, the 111-page volume, is WSG 88–2, is available from the publisher at US$10.00.

A Guide to Frozen Fish and Products

Publication of "**The New Frozen Seafood Handbook** by Ian Dore has been announced by Osprey Books, now an imprint of Van Nostrand Reinhold, 7625 Empire Drive, Florence, KY 41042. Subtitled "A complete reference for the seafood business," it is an expanded edition of Dore's first book, "Frozen seafood—the buyer's handbook," which has been completely revised and updated with about twice the information.

It is presented in encyclopedia form, alphabetically, from Abalone, Additives, and Aden tails to Yellowtail, Yields (of fish flesh), and Zoos and aquaria. Concise and authoritative descriptions of the terms are provided for aspects of the frozen fisheries trade, including descriptions of hundreds of fish and shellfish items, information on how to recognize and identify various products and to avoid substitutions, data on names and nameing and related rules and approved market and common names, methods of determining and maintaining fish quality, problems to watch for with certain types of products. Also included is a 33-page section on scientific, common, and market names of commercially traded fishes.

Information on "economic fraud in the seafood business," is presented, along with health and nutrition data, delivery terms, defrosting methods, products available from the various species, FDA inspection and rejection of imported foodstuffs and rejection insurance, recalls, and much more. A reference section lists many other useful books and periodicals, newsletters relating to fisheries and the fish trade. Indexed, the 360-page hardbound volume costs $69.00, and would be a handy reference for those involved in the fish trade from processing and distributing to marketing or the restaurant trade.

Progress and Practices in Fisheries Management

Publication of a considerably revised and augmented second edition of "**Fish Population Dynamics**," edited by J. A. Gulland, has been announced by John Wiley & Sons, Inc., 605 Third Ave., New York, NY 10158. This second edition is subtitled, "The implications for management."

Included is a new and good introductory chapter by T. D. Smith, "Stock assessment methods: The first fifty years," which, based primarily on English language literature, analyzes important developments in assessing the abundance of fish stocks. Additional chapters review the relationship between the type of stock assessment and the data required for it, the collection of fisheries assessment data, length-based methods of fish stock assessment, and some fisheries management implications of recruitment variability.

Subsequent chapters discuss the fisheries, stocks and recruitment, and management of particular species or species assemblages: Pacific salmon, North Atlantic cod, tropical penaeid prawns, marine mammals, small shoaling pelagic fish stocks, and multispecies fisheries of the Irish Sea. D. Pauly then discusses fisheries research and the demersal fisheries of Southeast Asia, K. J. Sainsbury reviews the ecological basis of multispecies fisheries and management of a demeresal fishery in tropical Australia, and editor Gulland concludes with an overview of the problems of population dynamics and contemporary fishery management.

Since the first edition of this book appeared about 10 years ago, there have been a number of changes in the field, both politically and scientifically. The new edition reflects such changes, emphasizing practical applications and presenting the experiences of management of the various fisheries. In the last chapter, Gulland notes the degree to which stock assessment scientists can and have provided information to managers, how such advice or information might be improved in the future, and he calls for the treatment of stock assessment as a well-integrated part of the management process. With author and subject indexes, the 422-page hardbound volume costs $49.95, and it remains a fine text/reference on the topic.

Some Questions and Answers on Sharks

"**Sharks in Question**," by Victor G. Springer and Joy P. Gold, has been published by the Smithsonian Institution Press, 470 L'Enfant Plaza, Suite 7100, Washington, DC 20560. Subtitled "The Smithsonian answer book," it provides authoritative data on the biology and lives of many important species of sharks. Springer is a curator in the National Museum of Natural History's Division of Fisheries and Gold is an information specialist in the NMNH Department of Vertebrate Zoology, and they have combined to produce a handy reference on the many questions asked by the public about sharks, drawing on recent scientific research.

The book is divided into five parts, with Part I presenting a broad array of "shark facts," including how and why they swim, whether they sleep, their color, speed, sounds, size, lifespan, reproduction, prey detection, intelligence, food and feeding, and much more. Part 2 briefly reviews the "supersharks," the great white, whale shark, hammerheads, bull shark, blue shark, shortfin mako, basking shark, thresher shark, tiger shark, and the blacktip, gray, and whitetip sharks.

Part 3 is devoted to shark attacks—how serious the threat is, which species are dangerous, where and how attacks occur, and how to avoid or repel attacks. Part 4 discusses the utilization of sharks, how to become a shark specialist, and what more we can learn about them, while Part 5 provides appended material on shark classification, common and scientific names, and lengths of selected sharks. Indexed, the 187-page paperbound volume is a useful reference on shark

lore that can help answer most of the questions a general audience would have. Cost is $39.95 (cloth) and $15.95 (paper).

Mollusks, Crustaceans and Their Management

Publication of "**Marine Invertebrate Fisheries, Their Assessment & Management**" has been announced by John Wiley & Sons, Inc., 605 Third Ave., New York, NY 10158. The editor is John F. Caddy, a senior fishery resource officer with the Food and Agriculture Organization of the United Nations in Rome. The book presents case studies and review chapters in two parts, for crustaceans and for mollusks, coelenterates, and echinoderms, with altogether 31 contributions by more than 40 authorities in their respective fields.

In sum, the volume presents the current practices in the assessment and management of the various natural or "wild" stocks of marine invertebrates. In addition, methods of assessing and managing various finfish stocks are examined for their application to certain invertebrate resources.

The first set of case studies relate to shrimps, prawns, and krill—evaluating potential resources and ecological concerns with Antarctic krill; management of brown shrimp, *Crangon crangon*, in Dutch coastal waters; northern shrimp, *Pandalus borealis*, fisheries in the northwest Atlantic; research and management of U.S. Gulf penaeid shrimp fisheries by Edward F. Klima; and resource assessment and management perspectives of the penaeid prawn fisheries of Western Australia.

Additional case studies are given for lobsters and crabs—the southwestern Nova Scotia-Bay of Fundy lobster fishery, Western Australia rock lobster fishery, modeling the Norway lobster component of the Irish Sea multispecies fishery, managing the cyclic U.S. Pacific Coast Dungeness crab fishery by Richard D. Methot, the Florida stone crab fishery (in which only claws are harvested), British Isles crab fisheries and management, and the Northwest Atlantic snow crab fisheries. Special reviews are presented on coastal penaeid shrimp fisheries management, performance and selectivity of trap fisheries for crustaceans, population biology of decapods, and effort limitation in the Australian rock lobster fisheries.

For mollusks and other invertebrates, case studies are given for the California abalone by Mia Tegner; the Caribbean's queen conch; the impacts of the precious shell harvest and trade on conservation of rare or fragile resources; traditional management practices in the Chesapeake Bay oyster fishery; mechanized shellfish harvesting and its management in the offshore clam fishery of the eastern United States by Steven A. Murawski and Fredric M. Serchuk; hydraulic dredging of clam resources in the Adriatic Sea; Mutsu Bay scallop culture, stock enhancement, and resource management; giant clam fisheries and stock enhancement; management of the Saharan trawl fishery for cephalopods; population assessment, management, and fishery forecasting for *Todarodes pacificus*; Pacific and Mediterranean precious coral fisheries, and world echinoderm fisheries. Review chapters cover population dynamics and assessment of scallops, especially the sea scallop, *Placopecten magellanicus*; recent developments in research and management of wild stocks of bivalves and gastropods, and forecasting yield and abundance of exploited invertebrates by Michael J. Fogarty.

Indexed, the 752-page hardbound volume presents a great deal of well documented important information and sound reviews that would be useful to a broad audience, including invertebrate culturists, managers, and scientists. Cost is $79.95.

Arrangements for Local Fisheries Management

"**Co-operative Management of Local Fisheries**," subtitled "New Directions for Improved Management & Community Development," edited by Evelyn Pinkerton, has been published by the University of British Columbia Press, #303 — 6344 Memorial Road, Vancouver, B.C. V6T 1W5 Canada. It may be the first book to draw together information and experiences on the processes in Canada and the United States in which the management of fisheries resources is participated in by local groups or communities—often Native American.

Here, various authors, representing such communities as anthropologists, environmental planners, biologists, economists, fishery managers, and various tribal and government leaders, examine from their different perspectives the process of arriving at co-management of such resources as salmon, marine mammals, lobsters, clams, and other fishes. Since the need for many of these arrangements seem constitutionally mandated, this book will be of interest to a wide variety of persons in the fisheries field who are or will be involved in working with or toward such co-management arrangements. The various contributors examine the successes and setbacks under such arrangements and provide various guidelines for viable cooperative resource management.

Part one describes Indian-state co-management of fisheries in the U.S. Pacific Northwest, and specific topics include the evolution of tribal involvement in the region's fisheries management (primarily Washington), social learning in the redesign of fisheries management, and negotiating salmon management on the Klamath River.

Part 2 deals with nonindigenous commercial fishermen creating regional and local co-management programs—specifically examining lobster management in southwest Nova Scotia and the sharing of a clam revitalization project in New Jersey (the "spawner sanctuary" program), and Alaska's regional aquaculture associations and co-management of salmon in Southeast Alaska.

Part 3 addresses the evolving aboriginal management regimes under new state regulation—the Alaska Eskimo Whaling Commission's work, prospects for co-management of marine

mammals in Alaska, and the development of state/tribal co-management of Wisconsin fisheries. Part 4 looks at provisions in comprehensive claims for Native self-management, while Part 5 reviews tradition and innovation among Native fishermen in coastal British Columbia. A final chapter provides a multidisciplinary assessment of the future of fisheries co-management. As noted in the last chapter, co-management has been a difficult process with a number of problems yet to be overcome. This volume does a good job in outlining many of the problems, techniques, and successes used in a variety of fisheries co-management arrangements. The 299-page volume is indexed and costs $36.95 (cloth) and $21.95 (paper.).

Estuaries, Resources and Their Functions

Publication of "**Estuarine Ecology**" by John W. Day, Jr., Charles A. S. Hall, W. Michael Kemp, and Alejandro Yanez-Arancibia has been announced by John Wiley & Sons, Inc., 605 Third Avenue, New York, NY 10158. Day is with the Center for Wetlands Resources, Louisiana State University, Baton Rouge; Hall is with the State University of New York's College of Environmental Science and Forestry, Syracuse; Kemp is with the Horn Point Environmental Laboratories, University of Maryland, Cambridge; and Yanez-Arancibia is with the Instituto de Ciencias del Mar y Limnologia, Universidad Nacional Autonoma de Mexico, Mexico City.

The book is divided into six parts, with the first reviewing estuaries and estuarine ecology on simulated "trips" through three different estuaries (Massachusetts' North River, Louisiana's Barataria Bay, and Mexico's Laguna de Terminos), wherein readers are introduced to pertinent introductory material, basic definitions, theory, and selected issues. The second section discusses various physical considerations (estuarine geomorphology and chemistry and physical oceanography). Section three reviews estuarine plants (phytoplankton, salt marshes and mangrove swamps, and seagrasses) and primary productivity. Sections four and five, respectively, deal with reduced carbon and its fate in the estuary and the estuarine consumers—zooplankton, the estuarine bottom and benthic subsystem, the nekton, and the role of wildlife (the higher vertebrates—mammals, birds, reptiles, and amphibians) in estuarine ecosystems.

Finally, Section six, "humans and estuaries," devotes one chapter to estuarine fisheries—their variation, harvest, and management; and another to the human impact on estuaries. The "meat" of the book, of course, is in the central sections, where the authors review and discuss the estuarine primary producers, microbial ecology and organic detritus, and the estuarine consumers, following the flow of organic matter from production by plants, to processing and cycling by microbes, and onward through the consumer levels.

Information is provided on rates, patterns, and factors controlling primary production, the role of detritus in ecosystems, and on estuarine consumers—the zooplankton, benthos, nekton, and vertebrates. There are a few minor typographical errors (i.e., the caption for Figure 12.1 refers to trawl, "pursp" seine, and "long time" fishing gear), but overall this will be a fine textbook on estuarine ecology. Indexed, each chapter also contains many useful and rather recent citations to the literature. Hardbound, the 558-page volume costs $54.95.

HOW TO MANAGE A FISH FARM

Publication of the AVI book "**Aquaculture Management**" by James W. Meade has been announced by Van Nostrand Reinhold, 115 Fifth Avenue, New York, NY 10003. Compared with some other nations, the author notes that aquaculture opportunities in the United States still have great potential. Not a fish-culture manual, this new book is actually a handbook for the manager of a fish farm that gives guidance for the physical, biological, and human resources utilized by or impinging upon fish farms. Indeed, it includes an interesting chapter on business, government, and environmental ethics, discussing, among other items, whether fish have rights. In addition, professionalism and legislated ethics are reviewed for public domain resource managers.

The book is divided into two basic parts, with part one providing an overview of such topics as the principles of fresh and salt water fish culture systems, principles of culture systems management, approaches to using and managing human resources, aspects of marketing, fish life cycles and production strategies, water and health management, and ethics.

Part two then delves into quantitative approaches, such as production economics, necessary records for managerial analyses, production system limits, and production capacity assessment. Other chapters review decision-making tools and their use, and computer assisted decision support systems. Appendices provide specialized information on attributes and expectations for aquaculture system managers, suggested steps for learning to understand or "read" people, examples of enterprise budgets, cash flow, and credit repayment schedules; life-cycle costing, a sample calculation to determine how many fish can be reared in a tank getting 5 gallons per minute of water, and sample problems on production capacity assessment (PCA).

The author is section leader for fish culture and bioengineering research at the FWS National Fishery Research and Development Laboratory in Wellsboro, Penn. The book is a good, up-to-date handbook with sound information on business and people management, and it covers problems ranging from site selection through planning, production, water quality management, worker relations, aquatic health management, marketing, and much more. In addition, many selected references are listed for each chapter to guide managers to more specific information. Indexed, the 175 page hardbound book is sold for $49.95.

On the Development of Small-scale Fisheries

Publication of "**Deep Water, Development and Change in Pacific Village Fisheries**" by Margaret Critchlow Rodman has been announced by Westview Press, 5500 Central Avenue, Boulder, CO 80301. The volume is part of the Press' Development, Conflict, and Social Change Series, and it presents the results and analyses of a 15-year anthropological case study of general development issues from the point of view of both canoe fishermen and development workers in the Vanuatu Islands of the South Pacific.

Here, the author offers a case study of a fisheries development program of moderate, though not complete, success, and she describes how various Vanuatuans view it as well. She tells how the Vanuatuans are responding in cultural, as well as political and economic terms to the commercialization of their craft of small-scale fishing, and how, with their traditional self-reliance and independence, the islanders are coping with the change to more of a capitalist economy. The volume thus helps readers see the various development issues through the islanders' eyes. Beyond the small-scale fisheries, however, such large fishing nations as Russia and Japan are vying for entry or influence into the region's fisheries. Change is coming and the volume helps to highlight various important issues and problems for the small island communities and for the aid donors and development workers as well. Paperbound, the 173-page volume costs $18.95.

Rivers, Resources, and Channelization Projects

Rivers have been modified—straightened, diked, dredged, etc.—for many decades, and controversy over the processes has probably existed almost as long. Certainly there are a wide range of environmental impacts associated with it, particularly on the fisheries. Dealing with these issues is "**Channelized Rivers, Perspectives for Environmental Management**," by Andrew Brookes, published by John Wiley & Sons, Inc., 605 Third Avenue, New York, NY 10158. The author is a Reading, U.K., environmental consultant and he utilizes case studies from both U.S. and U.K. projects to illustrate his points.

Rivers have been channelized for many reasons, including flood control, land drainage, navigation, erosion control or prevention, and the like, but rarely, it seems, for fisheries enhancement. Here, the author reviews information from a variety of disciplines to illustrate various factors involved in the stability of natural river channels and how one might anticipate the consequences of a decision to modify a channel. Recovery of aquatic populations in modified channels often depends upon adjustments or alterations of the channel morphology, he notes, and he also discusses how geomorphology is used to develop alternative designs and strategies to minimize the impact on natural resources.

The author provides an overview of the needs and problems in channelization, and the methods and limitations of conventional engineering design. Legislation has altered some approaches to channelization and these are discussed in chapter 3.

Physical and biological impacts of channelization are covered in the third section, including data on impacts on fish and fisheries from studies in various nations, and the effects on riparian and wetland ecosystems, etc. Another chapter relates consequences downstream and well beyond the bounds of the channelization project. Another section lists many recommendations regarding revised construction procedures, as well as techniques for mitigation, enhancement, and restoration of aquatic ecosystems. A "postscript and prospects" section describes continued pressures for floodplain development, the increasing roles for environmental scientists, impact assessment, management measures, etc. The book seems more oriented to the engineering profession, but environmental assessment personnel who have to deal with the consequences of channelization projects may also find it useful. Hardbound and with author, geographical and subject indexes and a lengthy list of references, the volume costs $79.95.

Age, Growth References on Various Billfishes

NOAA Technical Memorandum NMFS-SEFC-224 by Dennis Lee is entitled "**Annotated List of Selected References on Age and Growth Studies of Istiophoridae and Xiphiidae**," and it is available from the author at the NMFS Miami Laboratory, 75 Virginia Beach Drive, Miami, FL 33149. This useful bibliography presents 83 annotated references with specific emphasis on ageing, ageing methods, growth rates, and regression and growth equation parameters that have been published on Istiophoridae and Xiphiidae. Also included is a subject index to facilitate data location.

Determination of age and growth is an integral part of life history investigations and a critical component for stock assessment of these species. This will be a handy reference for specialists, for the author has combed the billfish literature, particularly English language literature, and presented references which provide estimates of age and growth based on analyses of skeletal structures, tag release-recapture data, and size frequencies. Inference to age or derivation of various growth parameters is also included.

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